

**NASA CR-152449**

**DATA ANALYSIS REPORT  
PART I**

for

**ATS-F  
COMSAT MILLIMETER WAVE  
PROPAGATION EXPERIMENT**

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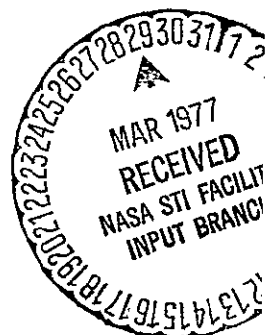
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16. Abstract  <p>The Data Analysis Report: Part I discusses the results of the 13/18 GHz COMSAT Propagation Experiment (CPE) to measure attenuation caused by hydrometeors along slant paths from transmitting terminals on the ground to the ATS-6 satellite and the effectiveness of site diversity in overcoming this impairment. The experiment is reviewed. The hardware used in the experiment is then discussed. This is followed by a brief discussion of the problems encountered in assembling a valid data base of rain induced attenuation data for statistical analysis. The procedures used to obtain the various statistics are then outlined. The graphs and tables of statistical data for the 15 dual frequency (13 and 18 GHz) sites and the 3 four-station (18 GHz) site-diversity locations are discussed, using the Fayetteville site as representative of the dual frequency sites and Boston as representative of the site-diversity locations.</p> <p>Cumulative rain rate statistics for the Fayetteville and Boston sites based on point rainfall data collected are presented. Extrapolations of the attenuation and point rainfall data are presented and discussed. Finally brief conclusions are drawn.</p> <p>Part II, which is bound in a separate volume, provides the complete set of plots and tables.</p>			
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## 1. SUMMARY

### 1.1 SCOPE

Part I of the data analysis report discusses the results of the 13/18-GHz COMSAT Propagation Experiment (CPE) to measure attenuation caused by hydrometeors along slant paths from transmitting terminals on the ground to the ATS-6 satellite and the effectiveness of site diversity in overcoming this impairment. The experiment is reviewed. The hardware used in the experiment is then discussed. This is followed by a brief discussion of the problems associated with data reduction, i.e., the problems encountered in assembling a valid data base of rain induced attenuation data for statistical analysis. The procedures used to obtain the various statistics are then outlined. The graphs and tables of statistical data for the 15 dual-frequency (13- and 18-GHz) sites and the 3 four-station (18 GHz) site-diversity locations are discussed, using the Fayetteville site as representative of the dual-frequency sites and Boston as representative of the site-diversity locations. These include for the dual-frequency sites cumulative fading (attenuation) statistics for the 13- and 18-GHz carriers; fade duration tabulations at 3, 6, 10, 15, 20, and 25 dB for each carrier; diurnal fade distribution histograms and tabulations; joint cumulative fading statistics for the 13-GHz carriers taken 1 to 10 at a time; and joint cumulative fading statistics of the same sort for the 18-GHz carrier at the dual-frequency sites. Finally cumulative fade statistics and 13/18-GHz fade depth correlation data are presented for the 13- and 18-GHz carriers for their joint on time.

For the diversity sites (as represented by Boston) cumulative attenuation statistics are presented for the four

18-GHz carriers (and the 13-GHz carrier at the dual-frequency site). This is followed by cumulative attenuation statistics for the joint on time of two 18-GHz carriers (six pairs, in all) and for the better of either, i.e., the diversity cumulative attenuation curve. The six diversity curves are then compared. Diversity improvement is then given. Cumulative rain-rate statistics for the Fayetteville and Boston sites, based on point rainfall data collected, are presented. Extrapolations of the attenuation and point rainfall data are presented and discussed. Finally brief conclusions are drawn.

Part II, which is bound in a separate volume, provides the complete set of plots and tables.

## 2. INTRODUCTION

### 2.1 GENERAL

The purpose of the CPE was to measure the attenuation at 13 and 18 GHz caused by rain, clouds and snow along the slant paths from ground transmitting terminals (GTTs) to the ATS-6 satellite and to analyze the resultant data base to establish the statistics of attenuation at 13 and 18 GHz, and the effectiveness of site diversity in overcoming impairments caused by this attenuation, for sites located in the eastern U.S.A. [1]

As shown in Figure 2-1, 15 dual-frequency (13 and 18 GHz) GTTs were located at 15 sites east of the Mississippi River and 9 single-frequency GTTs (18 GHz only) were located at 3 diversity sites, 3 to a site. Each diversity site consisted of a dual-frequency GTT and 3 single-frequency GTTs in a more or less east-west line spaced over about 24 miles (to achieve spacing increments in multiples of about 4 miles). The GTTs transmitted signals to the ATS-6 satellite which was in a geostationary orbit at about 94° West Longitude. The 13- and 18-GHz signals were received at the satellite by the COMSAT Labs-built ATS-6 CPE transponder [2] which translated them into two frequency bands near 4.15 GHz and relayed them to a central receiving and data acquisition site (DAQS) at Andover, Me., where the signals were digitized and recorded for later analysis at COMSAT Labs. [3]

When rainfall or other hydrometeors intercept the transmission path of radio signals in the GHz range, the signals are impaired. At frequencies above 10 GHz, attenuation due to rain events can reach relatively high levels. Therefore it becomes necessary for system design purposes to establish the cumulative statistics of such impairments and the effectiveness

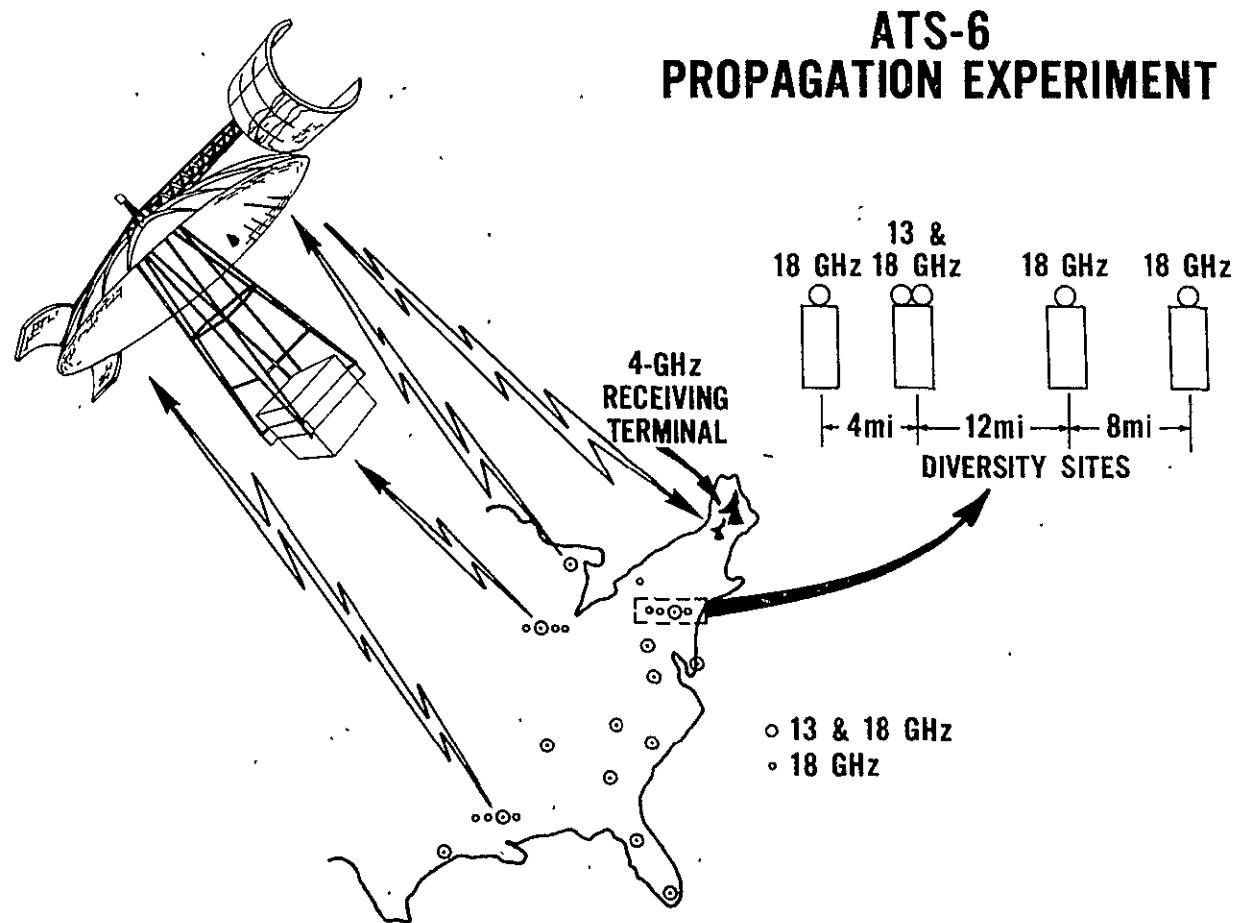


Figure 2-1. ATS-6 13/18-GHz COMSAT Propagation Experiment

of site diversity in overcoming them. The nature of rain in North America and Western Europe is such that widespread rain tends to be lighter, causing less attenuation, and heavy rain tends to be localized and of relatively short duration, tropical and maritime storms excepted. However, for most locations the effects of these latter events are statistically small, though they may not be completely negligible where periods of time on the order of 0.01% of the year are important.

The climate of the Eastern U.S.A. is a moderately rainy climate. Late spring and summer are the seasons for thunderstorms and heavy rain activity. This is followed by a season of occasional heavy rain and, more rarely, tropical storms, during the late summer and early fall seasons. Overall, there is sufficient heavy rain that the margins required to allow for the effects of rain induced attenuation at frequencies above 10 GHz are a significant consideration in the system design.

Because heavy rain in the U.S.A. typically falls from rain cells of relatively small diameter, on the order of 10 km, and the rain rate between rain cells is much lighter, site diversity should be an effective technique in the eastern U.S.A. for overcoming the rain-induced attenuation due to heavy cell-structured rain, and thus system margin requirements are expected to be reduced. Measurement of site diversity improvement as a function of intersite spacing is required to establish the relationship between margin and site separation.

## 2.2 EXPERIMENT

The CPE was designed to sample the effects of climate on earth-satellite links (13 and 18 GHz) at 15 wide-spread locations throughout the Eastern U.S.A., with minimum spacing of at



least 160 km. These locations were near Miami, Fla.; Atlanta, Ga.; Starkville, Miss.; New Orleans, La.; Nashville, Tenn.; Asheville, N.C.; Fayetteville, N.C.; Wallops Is., Va.; Clarksburg, Md.; Philadelphia, Pa.; Columbus, Ohio; Detroit, Mich.; Boston, Mass.; and Andover, Me. Three of these locales, Starkville, Columbus and Boston were also equipped with appropriately spaced 18-GHz space diversity terminals (see Figure 2-1 inset), thus providing the CPE with the capability of measuring the effectiveness of diversity as a function of spacing. About 50,000 hours of processed 13-GHz transmit path data and about 51,000 hours of processed 18-GHz transmit path data were collected in the 10 months of the experiment. Additionally, about 113,000 hours of processed point rain data at these sites was collected.

A significant body of data has been collected using the CPE and the analysis of this data provides a basis for system margin and site diversity spacing choices. The principal limitations of the CPE arose from data lost due to equipment failures (particularly in the 18-GHz transmitters), satellite attitude changes required by other experiments and projects, and the limited time during which the CPE was available in the U.S.A. (middle of July/74 to May/75).

### 3. DESCRIPTION OF CPE HARDWARE

A detailed description of the hardware for the CPE is provided under the NASA contract NAS 5-21616 report entitled, "ATS-F COMSAT Millimeter Wave Experiment: Final Hardware Report". [4] A summary of this report is given in this section. The link budgets for up- and down-links are given in Tables 3-1 and 3-2.

#### 3.1 CPE GROUND TRANSMIT TERMINALS

There were 15 dual-frequency (13 and 18 GHz) terminals and 9 single-frequency (18 GHz) terminals at the locations previously cited. The frequencies and designations of these GTTs are given in Tables 3-3 and 3-4. The frequencies, lying in two (10 MHz) bands from 17.74 to 17.80 GHz and 13.19 to 13.20 GHz, were chosen to minimize intermodulation products and their effects in the transponder. Figure 3-1 shows the Washington dual-frequency terminal. All dual-frequency GTTs are similar except for the Andover GTT, which was equipped with larger steerable antennas and mounted on the receive terminal horn antenna inside a radome. All single-frequency terminals are similar. Block diagrams of the dual-frequency and single-frequency GTTs are shown in Figures 3-2 and 3-3, respectively. The half-rack containing the transmit chain and recorder for a typical dual-frequency GTT is shown in Figure 3-4. The half-rack for the single-frequency GTT is basically similar but does not have a 13-GHz frequency generator or TWTAs. Performance of GTTs is given in Table 3-5. The cw signals originated in the frequency generators and were amplified in the TWTAs to approximately 28 W (7 W for the 18-GHz site diversity GTTs) and then were radiated

Table 3-1. Typical Up-Link Performance

Parameter	Attenuation Experiment		Diversity Experiment
	13 GHz	18 GHz	18 GHz
<u>Earth Station</u>			
Transmitter Max. Output Power (dBW)	14.0	14.0	7.0
Power Control Margin (dB)	0.2	0.2	0.2
Feeder & Comb. Losses (dB)	0.3	0.3	0.3
Antenna Peak Gain (dB)	32.2	32.2	32.2
Gain Loss (pointing error) (dB)	1.5	1.5	1.5
Gain Loss (polarization misalignment) (dB)	0.0	0.0	0.0
e.i.r.p. (dBW)	44.2	44.2	37.2
<u>Transmission Medium</u>			
Free Space Path Loss (dB)	207.2	210.0	210.0
Atmospheric Loss (dB)	0.2	0.5	0.5
Total Propagation Loss (dB)	207.4	210.5	210.5
<u>Satellite</u>			
Noise Temp. of Satellite Antenna (dB/K)	24.6	24.6	24.6
Repeater Noise Figure (dB)	10.0	10.0	10.0
Total Noise Temp. at Repeater Input (dB/K)	34.6	34.6	34.6
Satellite Antenna Peak Gain (dB)	26.5	29.8	29.8
Gain Loss in Direction of Station (dB)	0.8	1.0	1.0
Effective Antenna Gain (dB)	25.7	28.8	28.8
Effective G/T (dB[K <sup>-1</sup> ])	-8.9	-5.8	-5.8
Carrier Level at Repeater Input (dBW)	-137.5	-137.0	-144.0
C/T at Repeater Input (dB[W/K])	-172.1	-171.6	-178.6
Boltzmann's Constant (dB[W/K-Hz])	-228.6	-228.6	-228.6
C/N <sub>0</sub> at Repeater Input (dB-Hz)	56.5	57.0	50.0
Noise Bandwidth (dB-Hz)	70.0	70.0	70.0
C/N at Repeater Input (dB)	-13.5	-13.0	-20.0
Noise Power at Repeater Input (dBW)	-124.0	-124.0	-124.0
Repeater Gain in Linear Operation (dB)	100.8	109.3	109.3
Carrier Level at TWTA Output (dBW)	-36.7	-27.7	-34.7
Noise Level at TWTA Output (dBW)	-23.2	-14.2	-14.2

Table 3-2. 4-GHz Down-Link Performance.

Parameter	Attenuation Experiment		Diversity Experiment
	13 GHz	18 GHz	18 GHz
<u>Satellite</u>			
TWTA Output Power (dBW)	-36.7	-27.7	-34.7
Post-TWTA Losses (dB)	0.5	0.5	0.5
Radiated Power (dBW)	-37.2	-28.2	-35.2
Satellite Antenna Peak Gain (dB)	17.0	17.0	17.0
Gain Loss in Direction of Station (dB)	0.1	0.1	0.1
Effective Antenna Gain (dB)	16.9	16.9	16.9
e.i.r.p. in Direction of Station (dBW)	-20.3	-11.3	-18.3
<u>Transmission Medium</u>			
Free Space Loss (dB)	196.7	196.7	196.7
Atmospheric Loss (dB)	0.0	0.0	0.0
Total Propagation Loss (dB)	196.7	196.7	196.7
<u>Earth Station</u>			
System Noise Temp. (dB/K)	16.6	16.6	16.6
C/T Degradation (dB)	0.0	0.0	0.0
Antenna Peak Gain (dB)	56.6	56.6	56.6
Gain Loss (pointing error) (dB)	0.0	0.0	0.0
Gain Loss (polarization misalignment) (dB)	0.0	0.0	0.0
Effective Antenna Gain (dB)	56.6	56.6	56.6
Effective G/T (dB[K <sup>-1</sup> ])	40.0	40.0	40.0
Carrier Level at Receiver Input (dBW)	-160.4	-151.4	-158.4
C/T at Receiver Input (dB[W/K])	-177.0	-168.0	-175.0
C/T on Up-Link (dB[W/K])	-172.1	-171.6	-178.6
C/T Total (dB[W/K])	-178.2	-173.2	-180.2
Boltzmann's Constant (dB[W/K·Hz])	-228.6	-228.6	-228.6
Overall C/N <sub>0</sub> at Receiver Input (dB-Hz)	50.4	55.4	48.4
Noise Bandwidth (dB-Hz)	20.0	20.0	20.0
Overall C/N at Receiver Input (dB)	30.4	35.4	28.4
Minimum C/N for Phase Lock (dB)	3.0	3.0	3.0
Measurement Dynamic Range (dB)	27.6	32.4	25.4

Table 3-3. Diversity Terminals

Location	Latitude/ Longitude	Az/El	Station/CP	f (GHz)
Boston, Mass. Waltham	42°22'14"N/ 71°12'51"W	211.94°/ 35.89°	17/40	17.797419
Boston, Mass. Sudbury	42°21'56"N/ 71°25'56"W	211.66°/ 35.99°	18/39	17.791754
Boston, Mass. Cambridge	42°21'51"N/ 71°05'08"W	212.10°/ 35.84°	2/15, 38	13.192101 17.792138
Boston, Mass. Marlboro	42°20'39"N/ 71°30'34"W	211.58°/ 36.04°	19/37	17.792363
Columbus, Ohio Mechanicsburg	46°01'09"N/ 83°30'12"W	196.07°/ 42.44°	23/31	17.794138
Columbus, Ohio London	40°00'44"N/ 83°21'43"W	196.29°/ 42.42°	21/34	17.793260
Columbus, Ohio Scientific Advances, Inc.	40°00'18"N/ 83°06'17"W	196.67°/ 42.36°	22/32	17.793816
Columbus, Ohio Ohio State University	40°00'10"N/ 83°02'41"W	196.76°/ 42.35°	3/14, 35	13.192416 17.792918
Starkville, Miss. Mathiston	33°33'54"N/ 89°07'16"W	188.78°/ 50.61°	26/10	17.798325
Starkville, Miss. Adaton	33°29'22"N/ 88°56'32"W	189.11°/ 50.67°	24/28	17.794782
Starkville, Miss. Mississippi State University	33°26'50"N/ 88°47'51"W	189.93°/ 50.70°	4/13, 33	13.192863 17.793596
Starkville, Miss. Sessums	33°25'09"N/ 88°42'50"W	189.54°/ 50.72°	25/17	17.798122

Table 3-4. Dual Frequency Terminals

Location	Latitude/ Longitude	Az/El	Station/CP	f (GHz)
Andover, Maine COMSAT Earth Station	44°38'10"N/ 70°45'20"W	211.44°/ 33.59°	8/9, 26	13.194266 17.795646
Detroit, Michigan Selfridge Air Force Base	42°36'22"N/ 82°50'55"W	196.24°/ 39.53°	7/10, 27	13.193705 17.795416
Philadelphia, Pa. McGuire Air Force Base	40°01'52"N/ 74°34'35"W	208.13°/ 39.53°	9/8, 25	13.194596 17.795868
Washington, D.C. Clarksburg, Md.	39°13'15"N/ 77°16'33"W	205.42°/ 41.38°	10/7, 24	13.195083 17.796096
Wallops Island, Va. Burton's Cave	37°38'48"N/ 75°39'27"W	208.49°/ 42.30°	20/11, 36	13.193492 17.792599
Nashville, Tenn. Fort Campbell	36°38'36"N/ 87°26'55"W	190.89°/ 46.93°	11/6, 23	13.195697 17.796301
Asheville, N.C. Fort Bragg	35°12'05"N/ 82°52'32"W	198.84°/ 47.73°	12/5, 22	13.195962 17.796535
Fayetteville, N.C. Rosman NASA Station	35°09'03"N/ 78°59'26"W	204.97°/ 46.15°	13/4, 21	13.196242 17.792879
Atlanta, Ga. Georgia Tech	33°46'32"N/ 84°23'51"W	196.93°/ 49.39°	15/2, 19	13.197123 17.797260
New Orleans, La. NASA Michoud Missile Test Facility	30°00'57"N/ 89°54'37"W	188.13°/ 54.72°	14/3, 20	13.196768 17.797199
Tampa, Fla. MacDill Air Force Base	27°50'56"N/ 82°32'02"W	203.47°/ 55.09°	16/1, 18	13.197805 17.797860
Miami, Fla. Homestead Air Force Base	25°28'41"N/ 80°22'21"W	209.40°/ 56.54°	5/12, 30	13.193227 17.794475



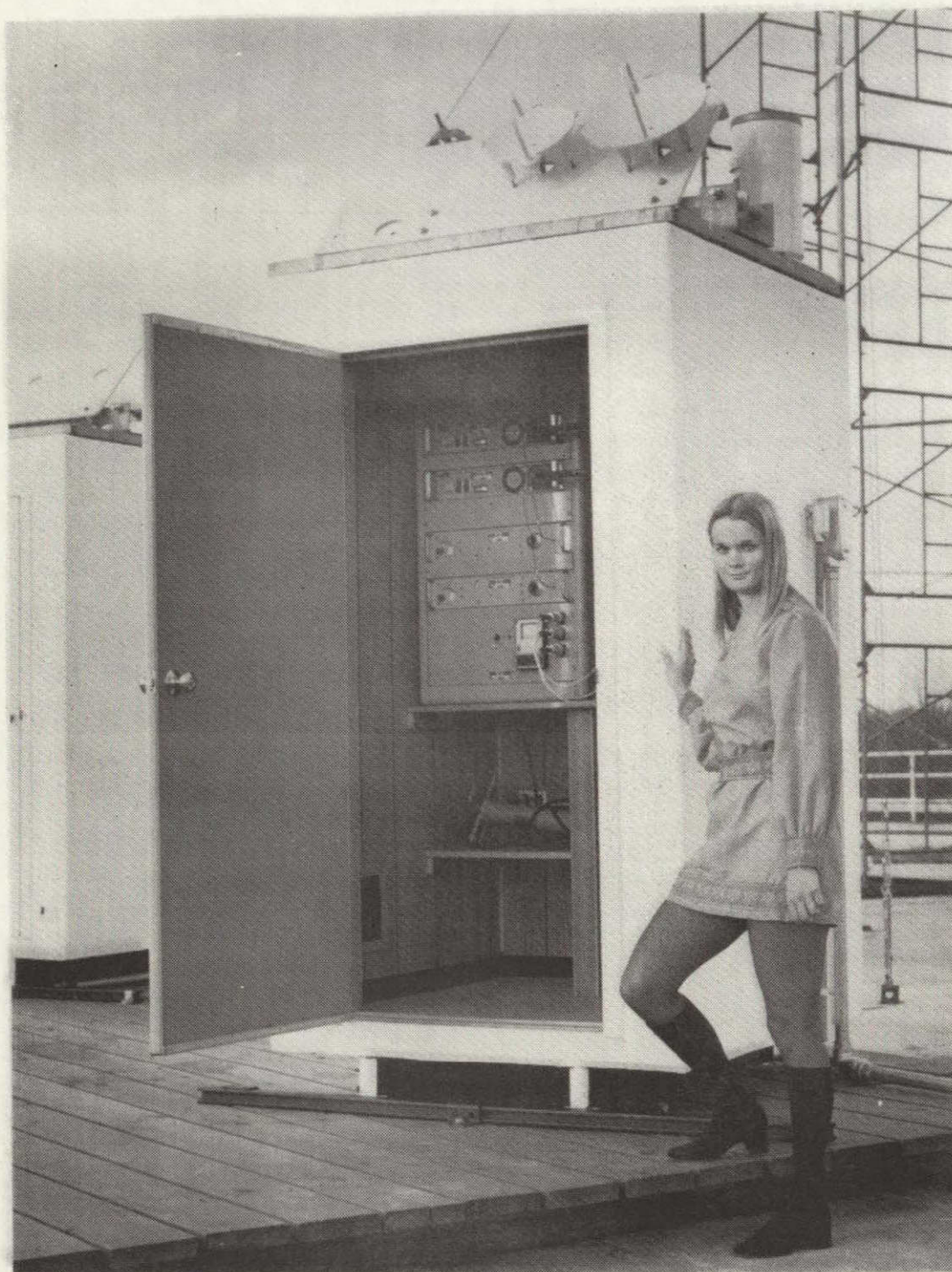


Figure 3-1. Dual-Frequency Radio Transmitter  
Mounted in Shelter

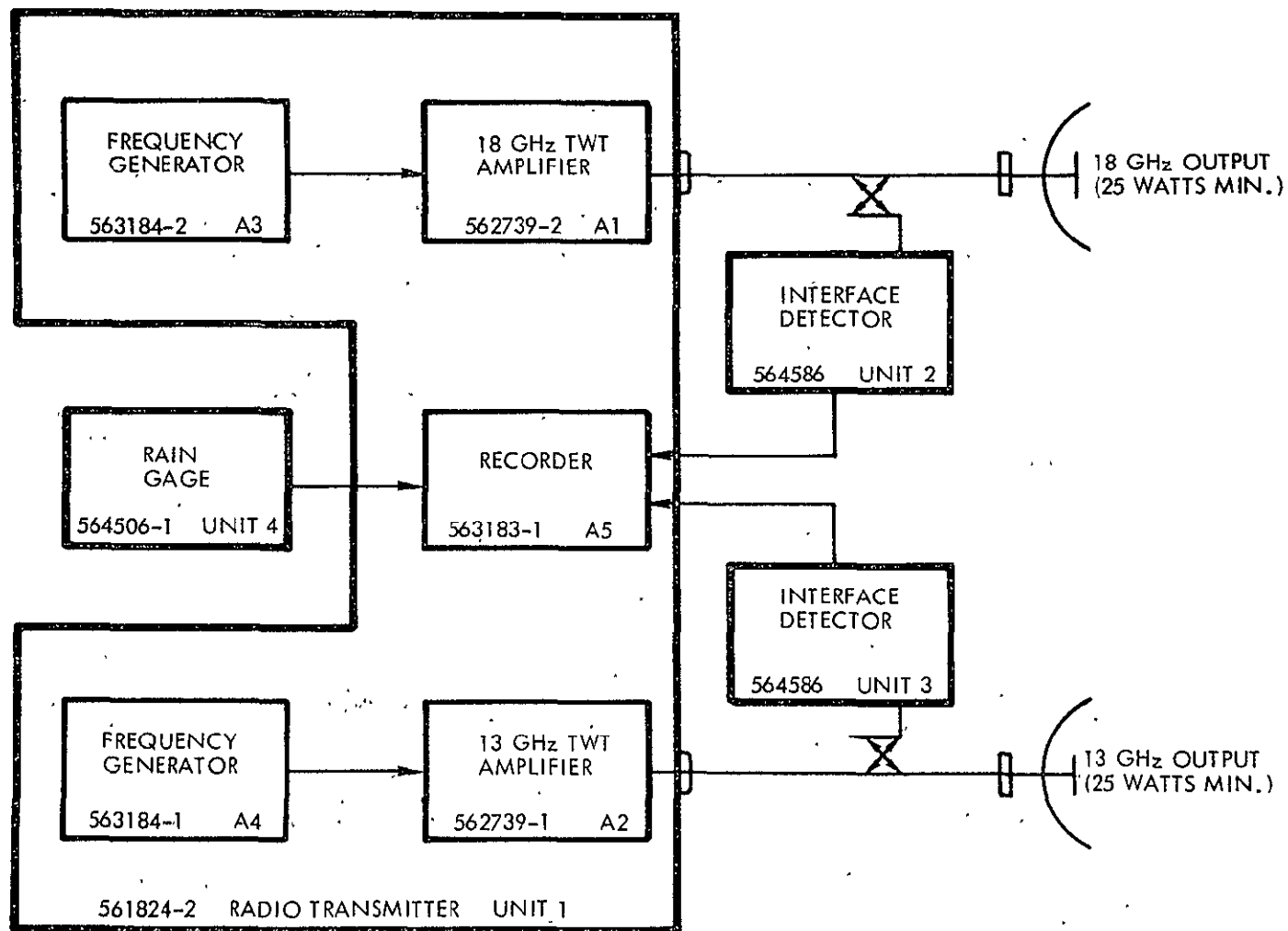


Figure 3-2. Functional Block Diagram of the Dual-Frequency Ground Transmitting Terminal



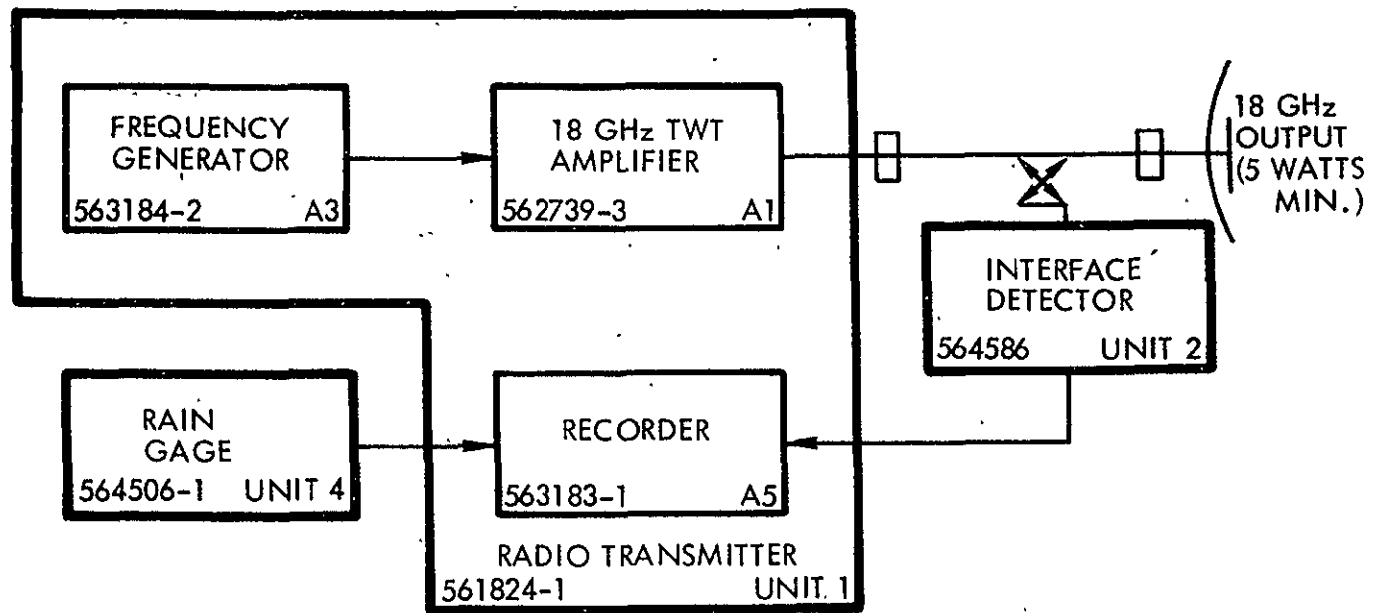


Figure 3-3. Functional Block Diagram of the Single-Frequency Ground Transmitting Terminal

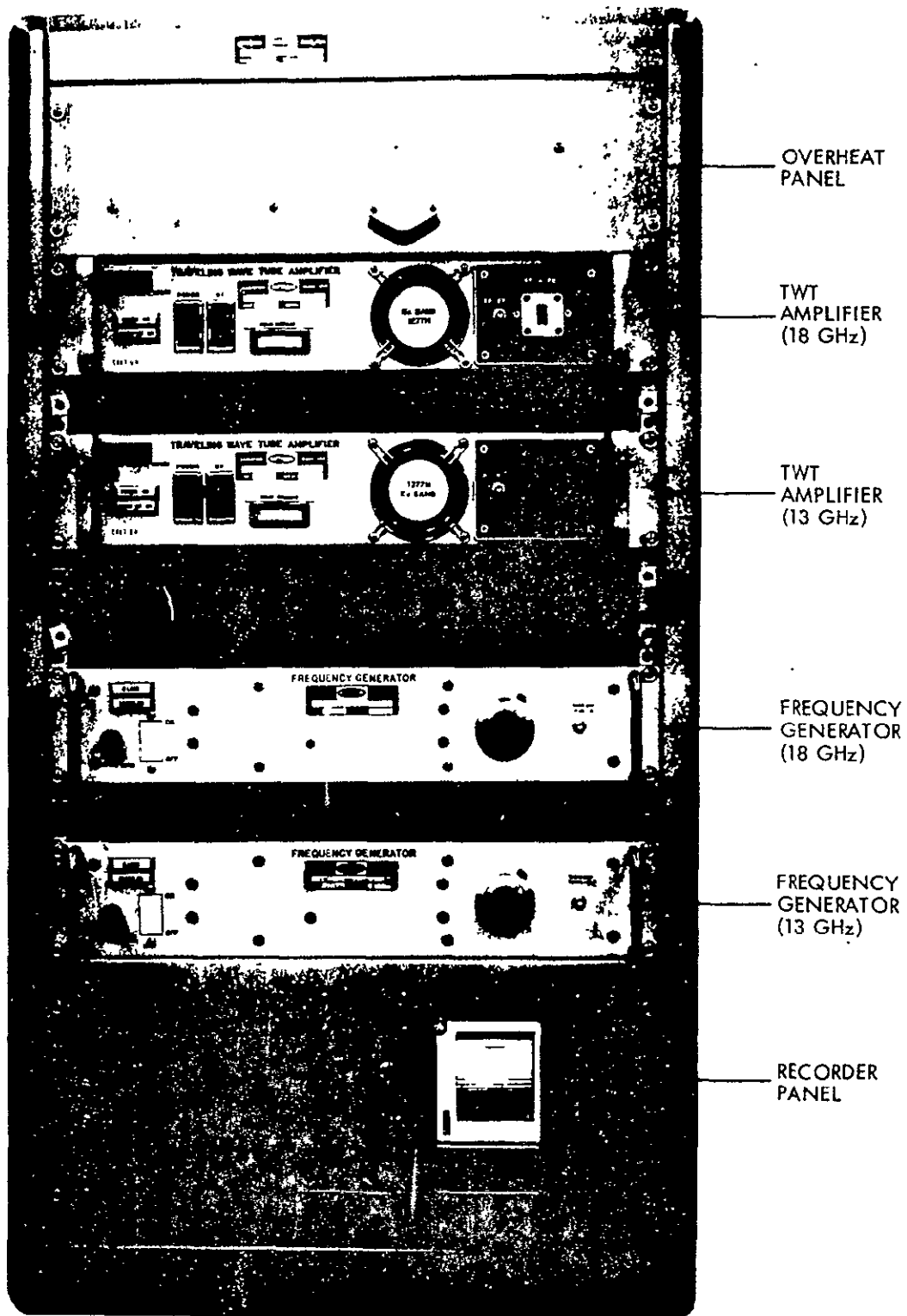


Figure 3-4. Dual-Frequency Transmit Rack

Table 3-5. Ground Transmitting Terminal  
Performance Parameters

Effective Isotropic Radiated Power	
17.8 GHz at Single-Frequency Terminal	39.2 dBW $\pm$ 0.5 dB
13.2 GHz at Dual-Frequency Terminal	46.2 dBW $\pm$ 0.5 dB
17.8 GHz at Dual-Frequency Terminal	46.2 dBW $\pm$ 0.5 dB
Antenna	
Beamwidth	
13.2 GHz	4° x 4° minimum
17.8 GHz	4° x 4° minimum
Size (13.2 and 17.8 GHz)	11 and 14 in.
Gain	
13.2 GHz	32.2 dB minimum
17.8 GHz	32.2 dB minimum
Polarization	Linear (rotatable to any plane)
Transmitter	
Power Output	
17.8 GHz at Single-Frequency Terminal	5 W minimum
13.2 GHz at Dual-Frequency Terminal	25 W minimum
17.8 GHz at Dual-Frequency Terminal	25 W minimum
Output Stability	$\pm$ 0.5 dB/72-hr period

towards the ATS-6 by the unsteered 4° half-power beam-width antennas. The transmitted power level was monitored and recorded to detect significant changes in power level. The point rainfall at the GTT was collected by the rain gauge and recorded for later reduction and analysis.

### 3.2 ATS-6 CPE TRANSPONDER

The transmitted signals were received at the satellite by a dual-frequency linearity-polarized elliptic-beam parabolic antenna with a gain of 26.5 dBi at 13 GHz and 29.8 dBi at 18 GHz. The antenna boresight was off-set approximately 2.9°E and 1°N of the satellite axis, to provide coverage of the GTT sides and DAQS site for satellite axis pointings over most of the CONUS. The signals were then processed by the ATS-6 CPE transponder shown in Figure 3-5. The transponder block diagram is given in Figure 3-6. The 13- and 18-GHz received signals were mixed with 9- and 14-GHz LO outputs into frequency bands 4.14 to 4.15 GHz and 4.16 to 4.17 GHz respectively. Then they were filtered and subsequently amplified by a three-stage tunnel diode amplifier. Both the 13- and 18-GHz frequency translators are redundant switchable chains. The two 4-GHz outputs were further filtered, then combined and then split to provide the drives for the redundant switched 4-GHz output amplifiers, each of which consisted of a second three-stage TDA followed by a TWTA. The redundancy and switching provided four paths through the transponder for the signals. Transponder performance (bench measurements on the flight unit) is given in Table 3-6. The ATS-6 provides a relatively benign environment. However, temperature changes were occasioned by the fact that the satellite was in a geostationary orbit, was three-axis stabilized, and had a changing thermal load in the experiments package where the transponder was located due to the



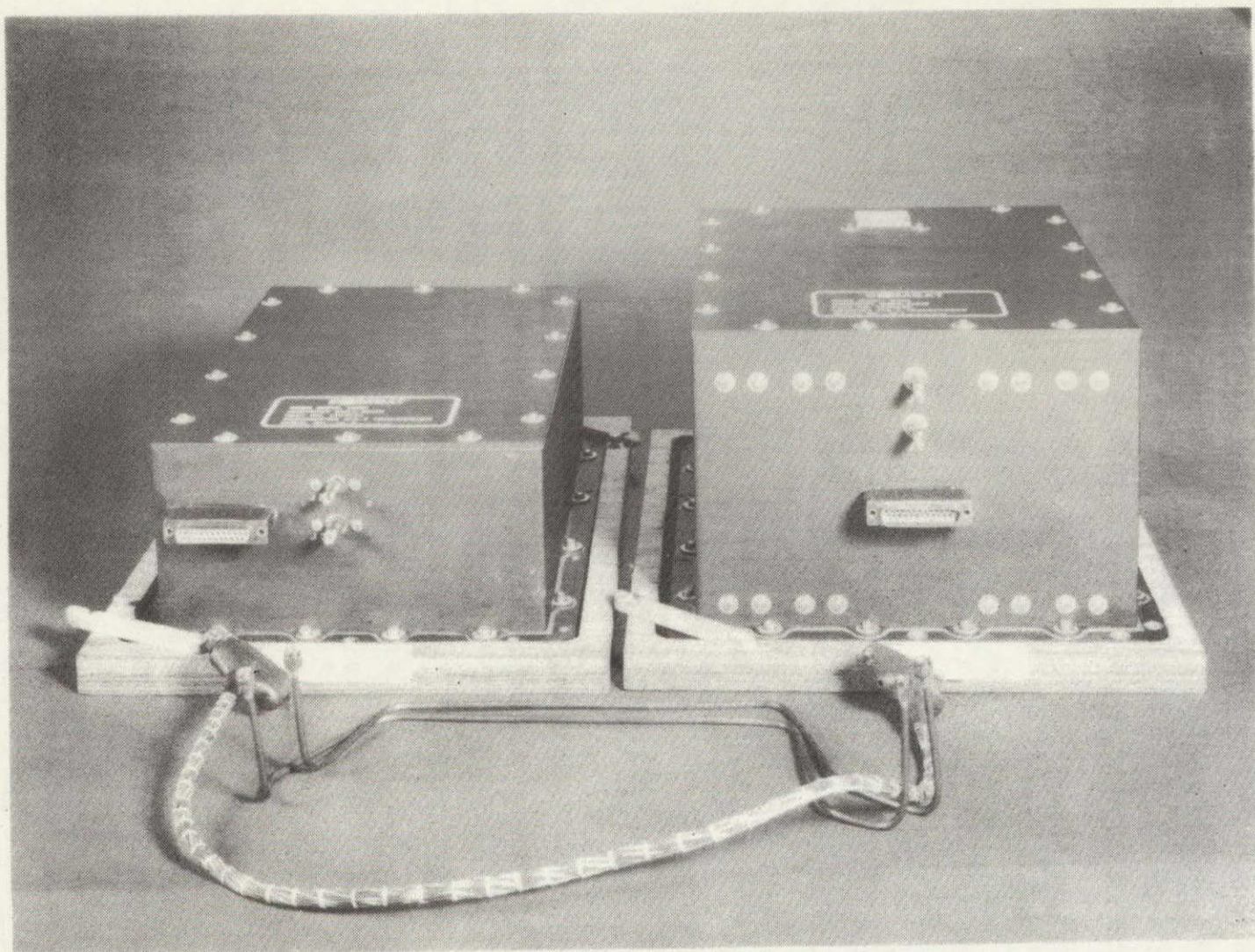


Figure 3-5. ATS-6 CPE Transponder



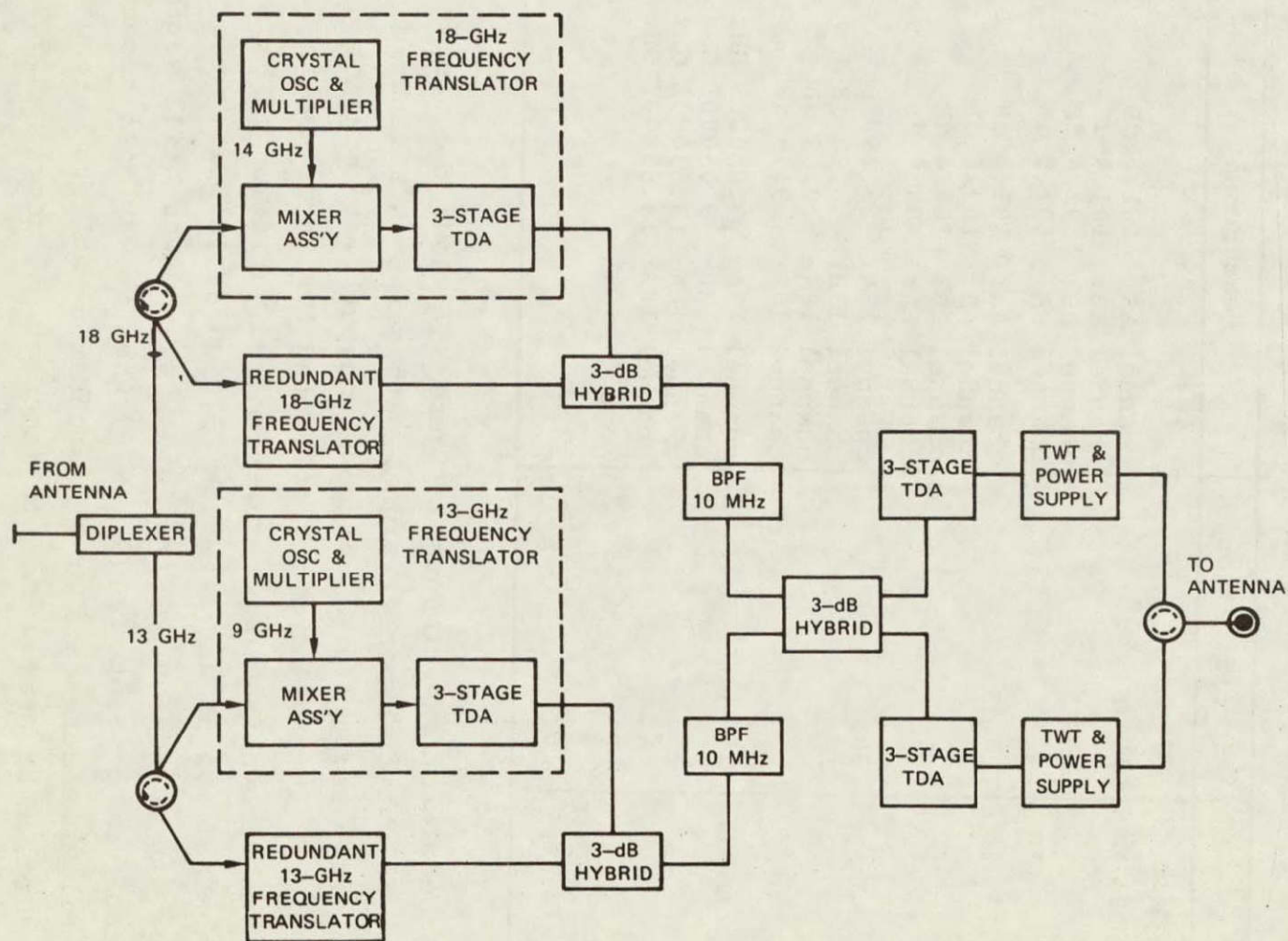


Figure 3-6. Overall Transponder Block Diagram

Table 3-6. Flight Transponder  
Performance

	Specification	Measurement
Overall Gain		
at 13,195 MHz	101 dB	channel AA: 101.1 dB channel AB: 101.8 dB channel BB: 102.4 dB channel BA: 101.8 dB
at 17,795 MHz	110 dB	channel AA: 109.4 dB channel AB: 109.6 dB channel BB: 109.4 dB channel BA: 109.9 dB
Noise Figure	<10.5 dB	channel 13A: 9.25 dB channel 13B: 8.98 dB channel 18A: 10.09 dB channel 18B: 9.78 dB
LO Frequencies	9.05 and 13.63 GHz	channel 13A: 9.050003 GHz channel 13B: 9.050001 GHz channel 18A: 13.630002 GHz channel 18B: 13.630002 GHz
DC Power	<14 W	10.9 W
Weight	<16.8 kg	14 g

changing schedule of experiments. Figure 3-7 shows the variation of the flight transponder signal path gains as a function of temperature. Temperature (and power output) were monitored and are included in the telemetry collected for later use in data reduction (to remove the temperature-induced variation of gain from the nominal 101 dB at 13 GHz and 110 dB at 18 GHz). The transponder was turned on on June 10, 1974, and was still performing flawlessly as of September 7, 1976, when it was most recently used. In-orbit measurements of transponder parameters were within measurement error of prelaunch data (see ref. 4, section 3.5.2).



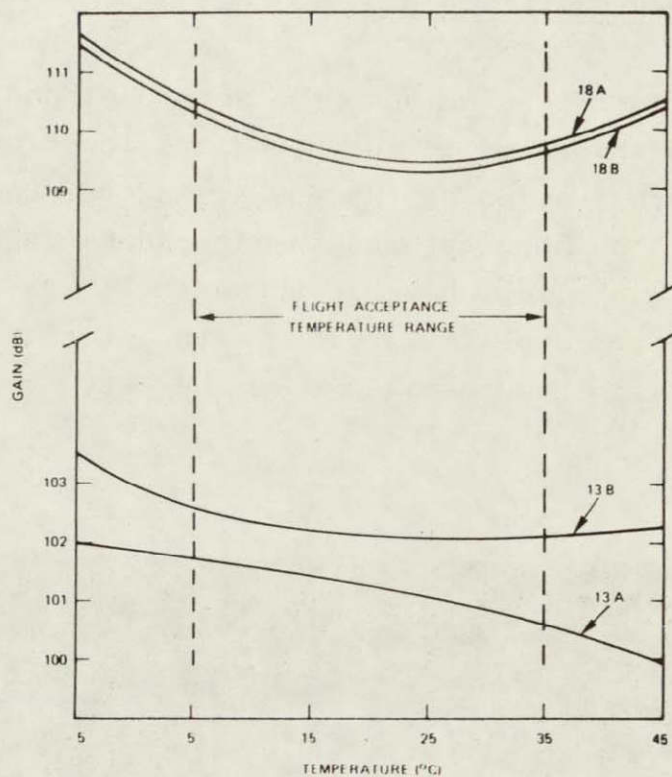


Figure 3-7. Flight Transponder Gain vs Temperature

The transponder drives a 4-GHz, 17-dB gain earth coverage horn to provide the down-link radiation. This combination of up- and down-link antenna pattern coverage permitted the CPE to continue operation for a wide range of ATS-6 pointing conditions. For example, this permitted measurements to be conducted in August and September 1976, while the ATS-6 was en route to a new western station, with GTTs at COMSAT Labs, Clarksburg, Md. while the receiver and DAQS were in Buitrago, Spain. Another feature of the transponder that permitted maximum on-time was its low-power consumption (less than 11 W measured) which permitted the ATS-6 CPE transponder to remain on 24 hours-per-day, almost every day.



The ground receive and DAQS were designed and built at COMSAT Labs, and installed in the upper and lower cabs of the horn antenna earth station at the COMSAT Andover Earth Station at Andover, Me. The horn antenna in its radome is shown in Figure 3-8. The signal flow chart is shown in Figure 3-9. The antenna and parametric amplifier, along with antenna tracking and pointing system were made available to the CPE.

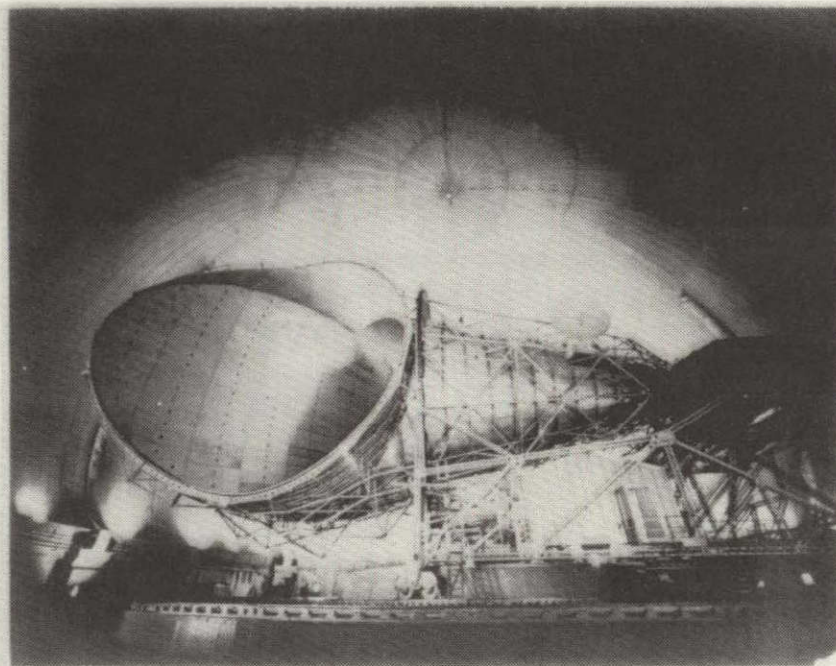


Figure 3-8. Horn Antenna,  
Andover, Me.

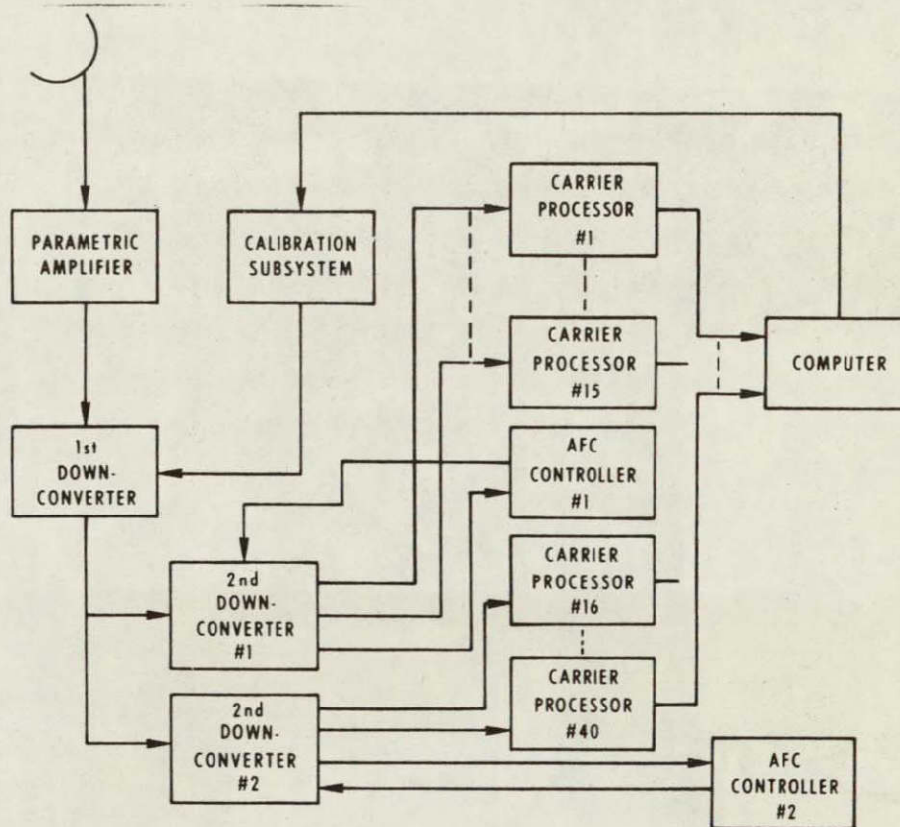


Figure 3-9. DAQS Signal Flow Block Diagram

### 3.3.1 GROUND RECEIVE EQUIPMENT

The remaining receive equipment was installed in two sections. The upper cab unit, shown in Figure 3-10, consisted of the calibration system and first down-converter. Figure 3-11 is a block diagram of the first down-converter and Figure 3-12 is a block diagram of the calibration subsystem. The system was calibrated three times daily with signals injected between the antenna and the LNA, from reference levels above the strongest signal anticipated to 40-dB down from the reference level. The first down-converter amplified the 4-GHz signals, mixed them down to



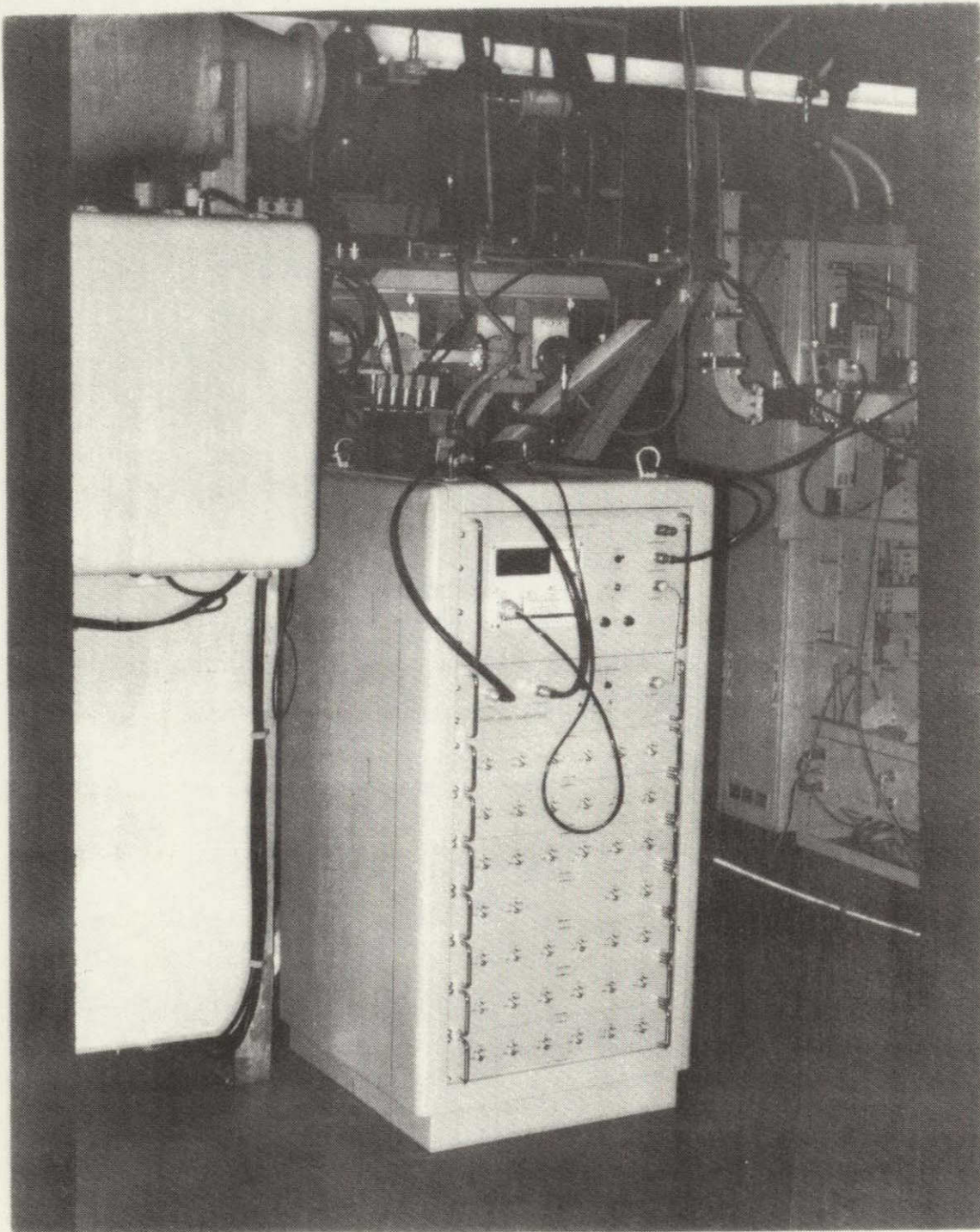


Figure 3-10. Upper Cab Equipment

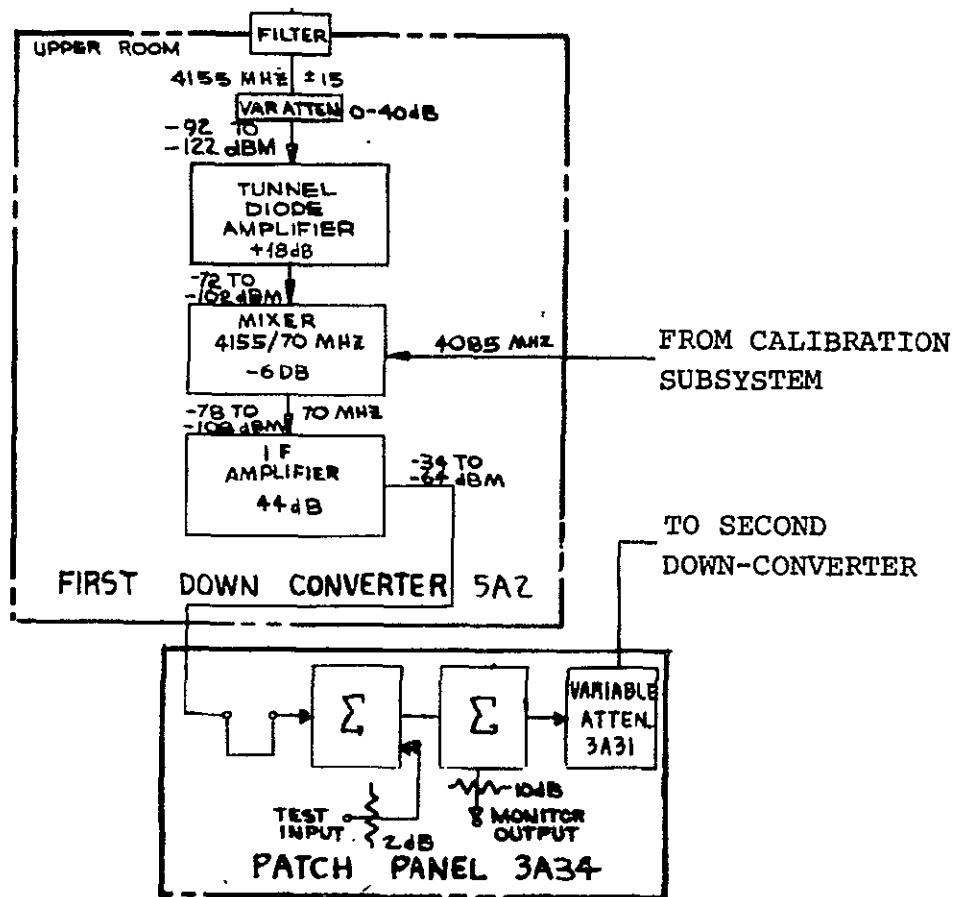


Figure 3-11. First Down-Converter Block Diagram

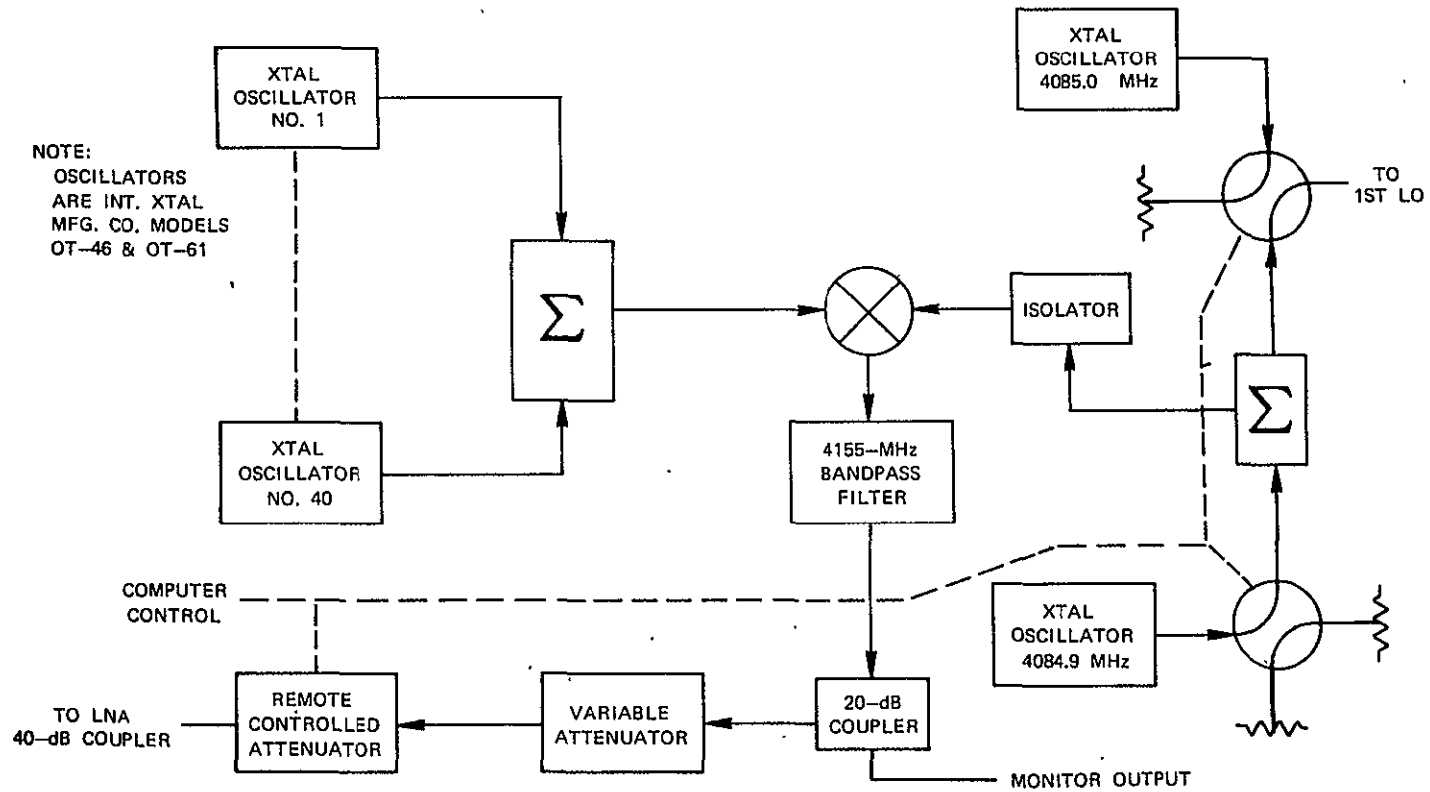


Figure 3-12. Calibration Subsystem Block Diagram

70 MHz and then provided IF amplification. The 70-MHz signals were brought to the lower cab unit via a long-run of coaxial cable. The lower cab unit consisted of the second down-converter, the AFC system, the carrier processors, and auxiliary monitoring equipment (Voltsmeters for each carrier processor and a multichannel chart recorder), and the DAQS. The second down-converter, shown in Figure 3-13, isolated the 18-GHz and 13-GHz bands (10 MHz each) into two channels, down-converted both bands to 25 MHz  $\pm$  5 MHz, divided the signals into fifteen 13-GHz channels and twenty five 18-GHz channels, and provided further amplification to drive the 40 carrier processors. Each carrier processor filtered its own individual signal, i.e., carrier, and down-converted it to 1.05 MHz. Then the carrier went through a phase-locked loop receiver and detector and emerged as a dc voltage. The carrier processor block diagram is given in Figure 3-14. From the link budgets given earlier in Tables 3-1 and 3-2, it is seen that the clear sky carrier level at the receiver input is -160.4 dBW at 13 GHz and -151.4 dBW for the dual-frequency GTT 18-GHz carriers and -158.4 dBW for the single-frequency GTT 18-GHz carriers. The transfer characteristics of the receive system to the output of a typical carrier processor is shown in Figure 3-15. The dynamic range of the individual carrier processors was at least 40 dB down to loss-of-lock from the reference 0-dB level of -119 dBm. The best processor had a 55-dB dynamic range to loss-of-lock. Dynamic range to automatic reacquisition of the system was greater than 31 dB for the 18-GHz dual-frequency carriers, greater than 26 dB for the 18-GHz single-frequency carriers and greater than 23 dB for the 13-GHz carriers, which about matches design expectations (see reference 1, Table 1). The carrier processor assignments were previously shown in Table 3-3.

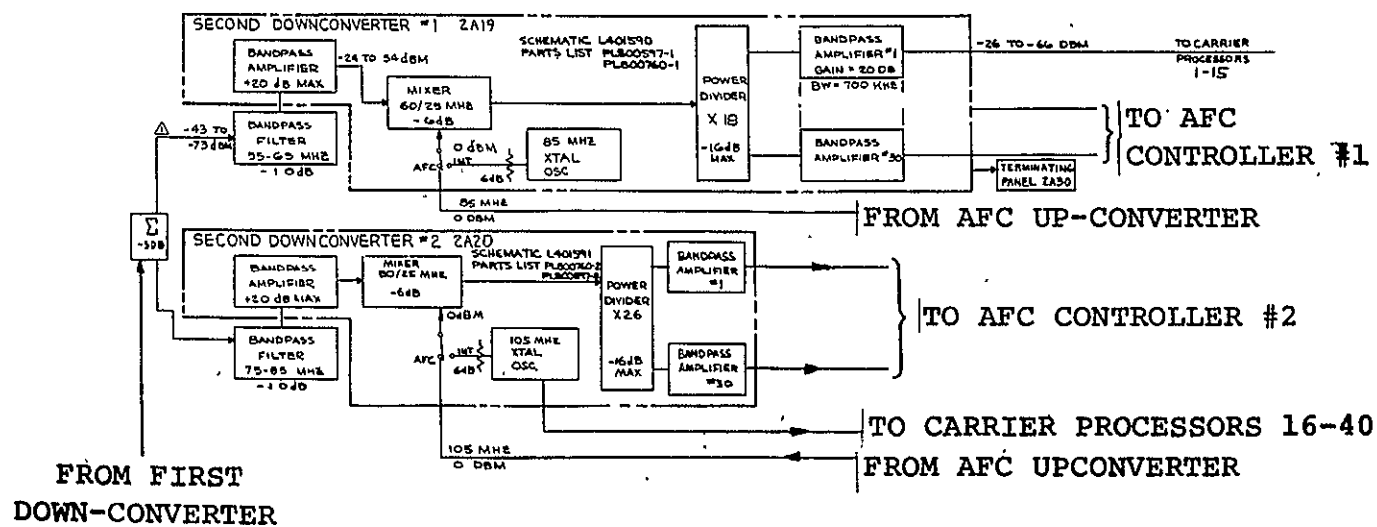


Figure 3-13. Second Down-Converter Block Diagram

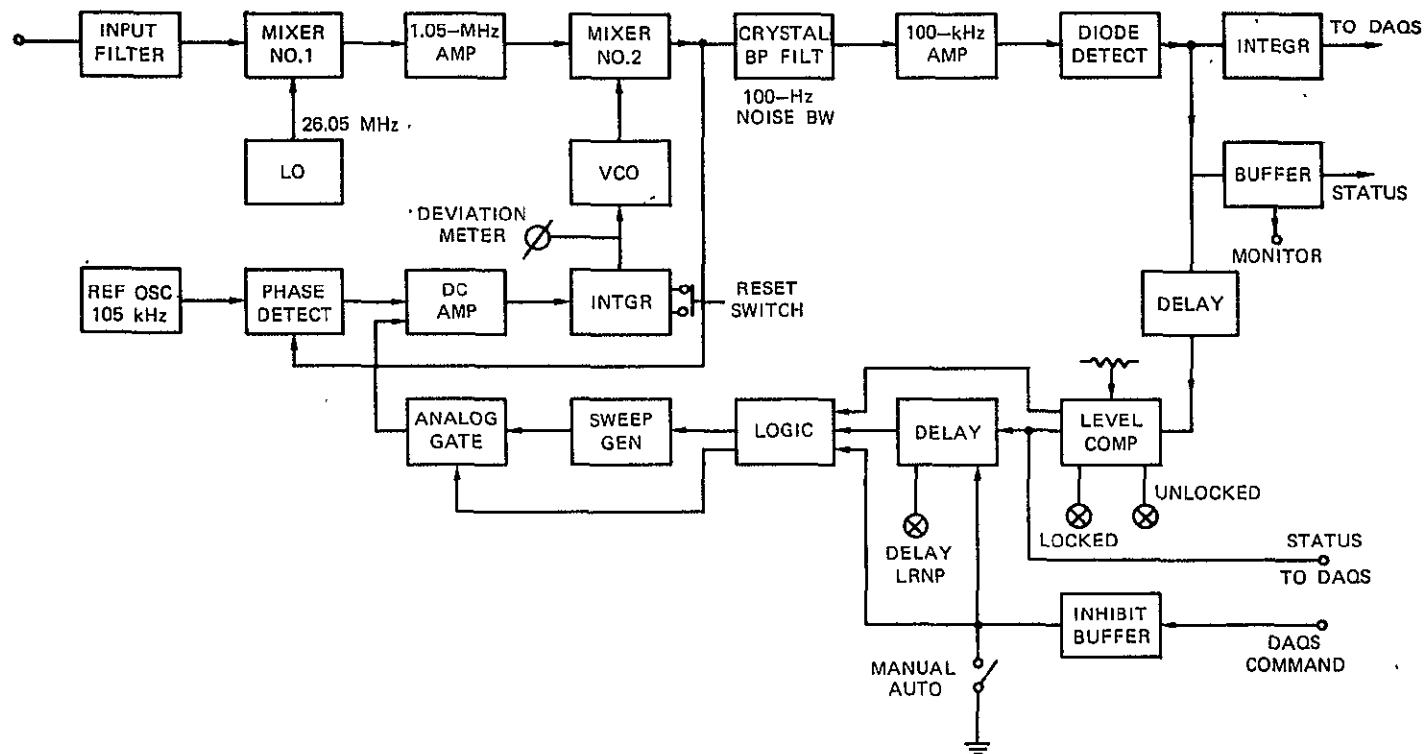


Figure 3.14. Carrier Processor Block Diagram



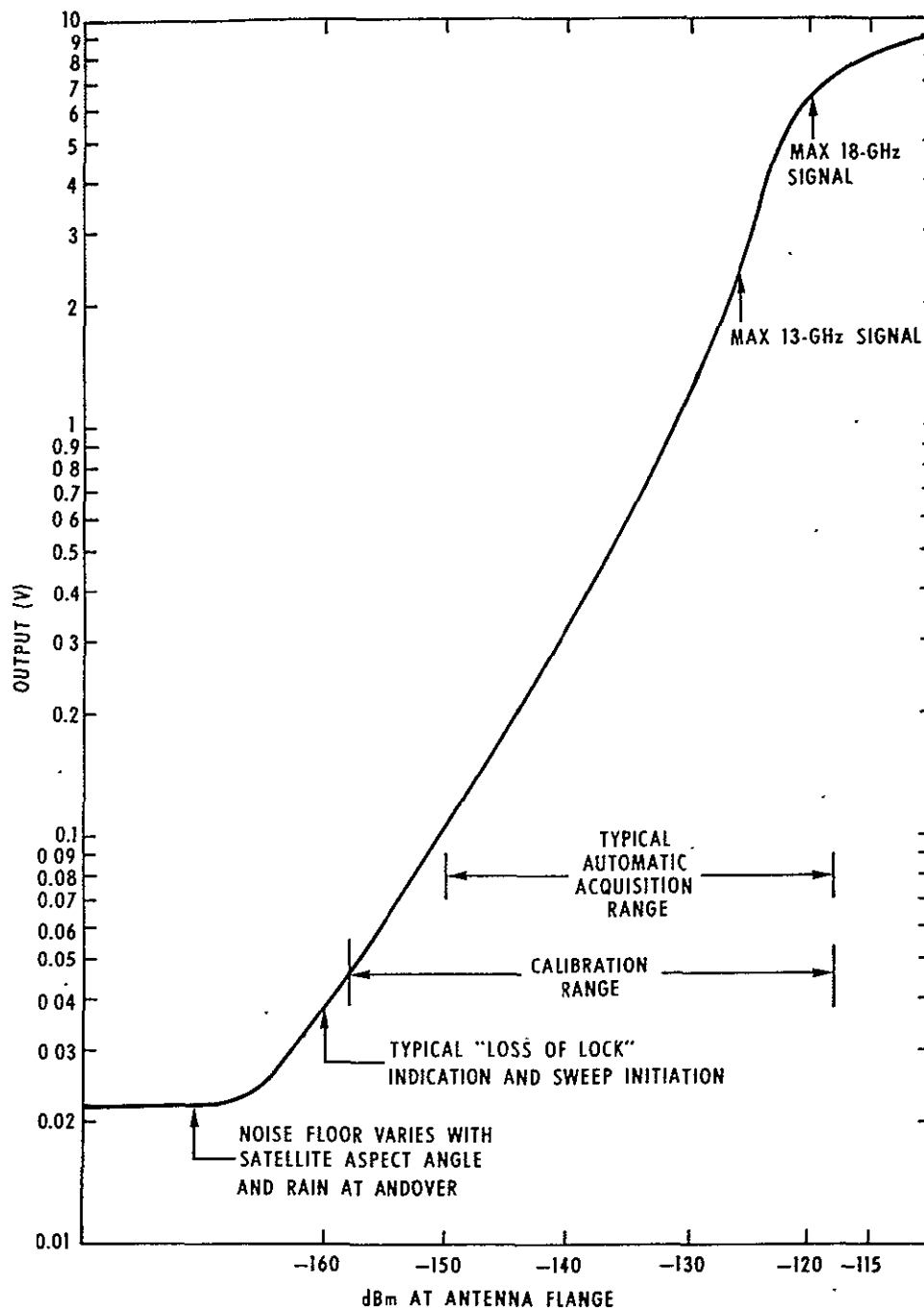


Figure 3-15. Typical Carrier Processor Transfer Characteristic

The outputs of the carrier processors were used simultaneously to drive the DAQS individual dc Voltmeters for visual indication and, if desired, by appropriate switching, a channel of the two-channel chart recorder. The lower cab unit of the receive equipment and the DAQS are shown in Figure 3-16. The DAQS consists of the left rack and the teletype terminal. The 40 (+ 2 spares) carrier processors are located on the rows of instrumentation across the upper part of the center and right racks.

### 3.3.2 DATA ACQUISITION SYSTEM

The data acquisition, calibration control, on-site processing and recording was performed by the DAQS. A block diagram of the DAQS is shown in Figure 3-17. The system normally operated in the power measurement mode. In this mode all 40 carrier processor outputs were sampled once every second. These samples were digitized and then read into computer memory. They were then, in real time, converted to dB values referred to reference by interpolation between levels established in the most recent calibration, using tables, from the reference level, 0 dB, to 40-dB down from reference (refer to Figure 3-15), one table for each carrier. Nine consecutive measurements (normally 9 seconds of data), were stored in an array in core, along with time codes, and then blocked and recorded on magnetic tape. Normally, a tape was mounted for each day. Subsequently these tapes were forwarded to COMSAT Labs for processing on the IBM 360/65 central computer.

The computer could also calibrate on command, the receive system and store (in the computer memory) and print (on the ASR-33 teletype) the calibration tables for each carrier processor. This sequence was normally initiated by push button, three times daily, at about 8-hr intervals. The computer commanded



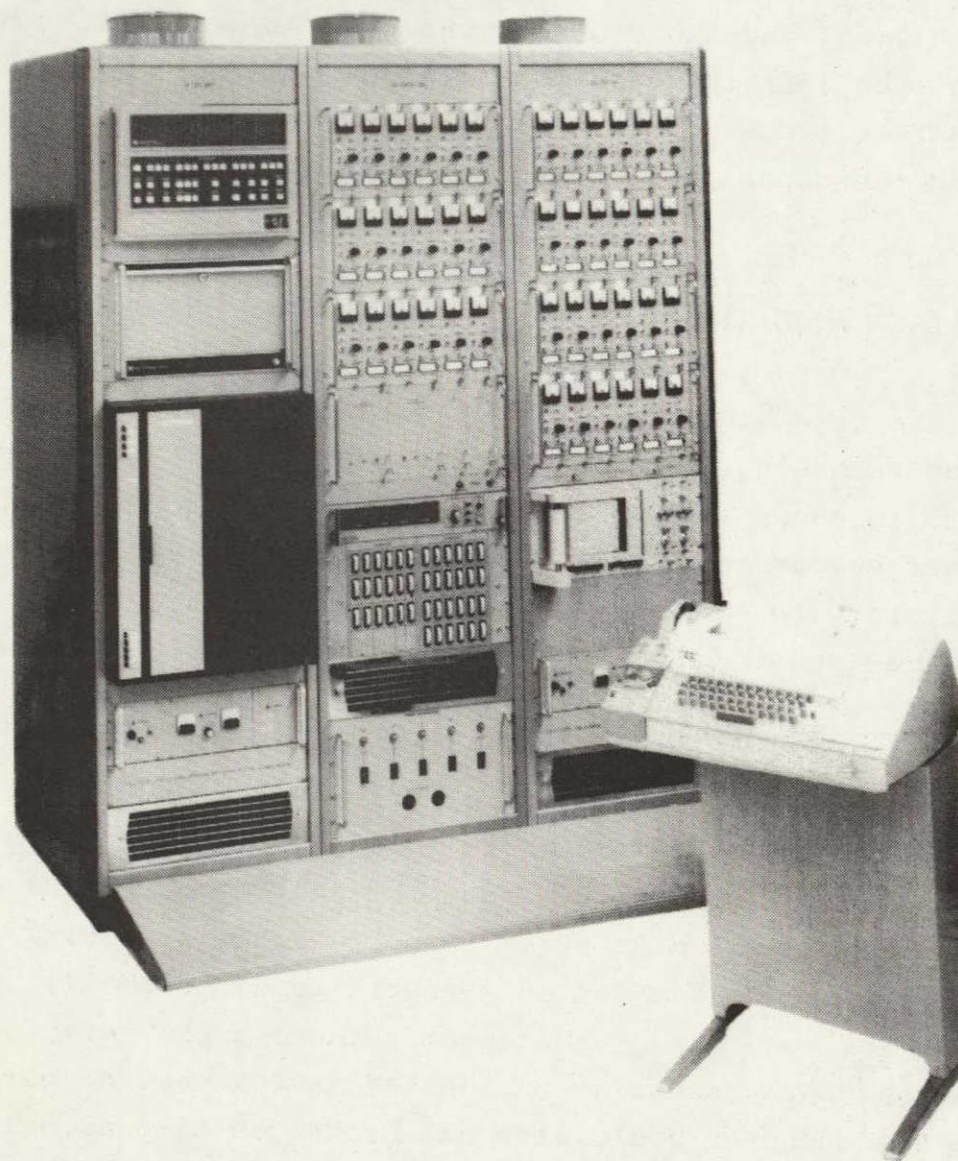


Figure 3-16. Lower Cab Equipment

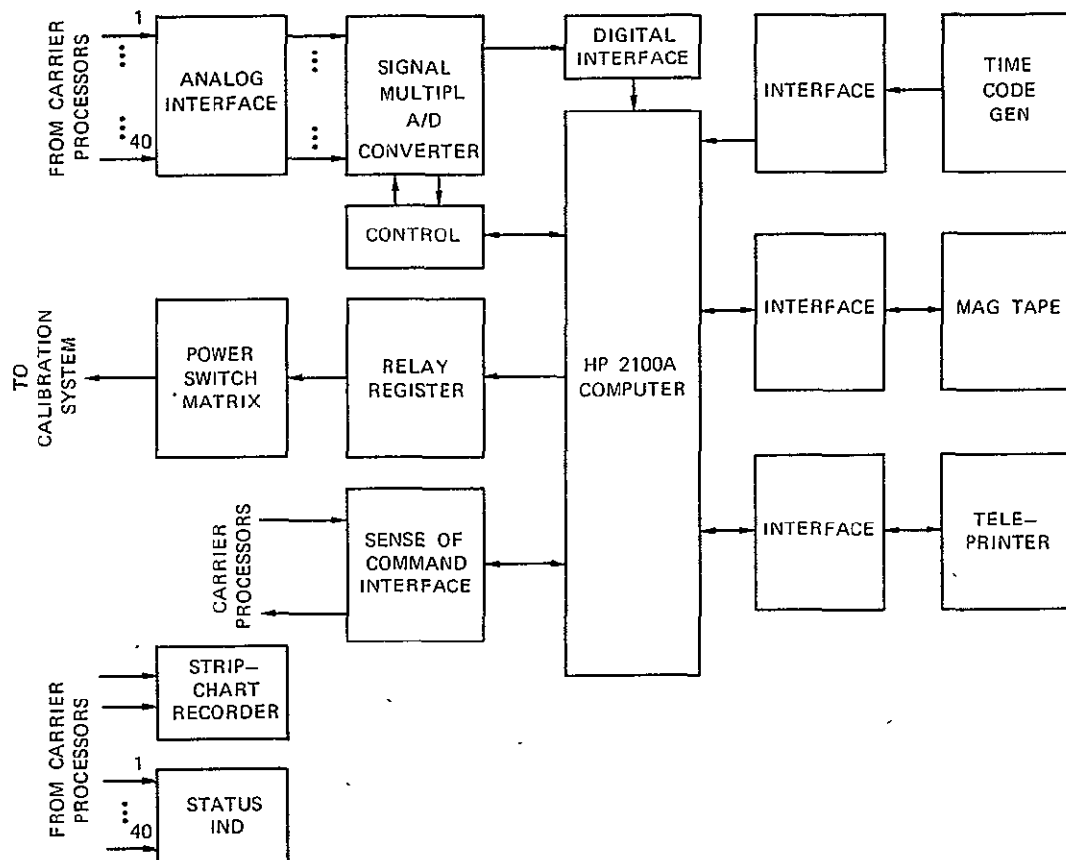


Figure 3-17. Data Acquisition System Block Diagram

the calibration unit and the drives for motor driven attenuators to set levels from 0-dB reference to -40-dB reference, in 5-dB steps. It then sampled the carrier processor outputs in sequence, 5 times at each level, averaged the 5 samples for each processor at each level, stored the results in core, and printed them on the teletype. The software to perform these functions and certain displays, and analysis and trouble shooting functions was developed at COMSAT Labs.

The receive and DAQS equipments have functioned properly, both at the Andover, Me. site and at the Buitrago, Spain site where they were installed as part of a CPE in Europe and India effort just recently concluded. There were only a very few equipment failures, and those failures that lost appreciable data were related to the purchased computer.

Overall, it is fair to say that there were no reliability or performance problems with the CPE transponder whatsoever, and few reliability or performance problems with the receive and DAQS. The main cause of loss-of-data due to the hardware was the lack of reliability and design problems in the GTTs. Additionally, much data was lost due to the ATS-6 schedule requiring pointings and beam motion rates not compatible with the CPE.

#### 4. DATA PROCESSING

Upon examining the contents of a raw data tape from the DAQS, a section of which is shown plotted in Figure 4-1, it immediately becomes apparent that in addition to the attenuation caused by rain (indicated at the right, between about 2230 and 2300 GMT, on two carriers) there are signal level variations that have nothing to do with attenuation due to rain along the individual slant paths. A few are marked on the topmost carrier trace. The problem then was to sort out the data related to changes in path attenuation that were produced by rain from data related to changes produced by other factors, and then to process the rain influenced data base. The processing required to accomplish this is described in detail in the Data Processing Report on the ATS-F COMSAT Millimeter Wave Propagation Experiment [5]. In this section the procedures which were used to produce a data base suitable for data reduction and analysis, that is, a data base from which the unwanted signal level changes have been removed, are summarized.

##### 4.1 PREPROCESSING OF RAW DATA TAPES

The ATS-6 was placed in a geostationary orbit inclined at  $1.8^\circ$  such that the forces that perturbed the orbit tended to reduce the initial inclination at a rate of about  $0.07^\circ$  per month. The satellite therefore moved back and forth across the GTT antenna beams diurnally, causing diurnal variations of signal level. These effects appear in Figure 4-2 as the more or less sinusoidal variation over the entire day. Other

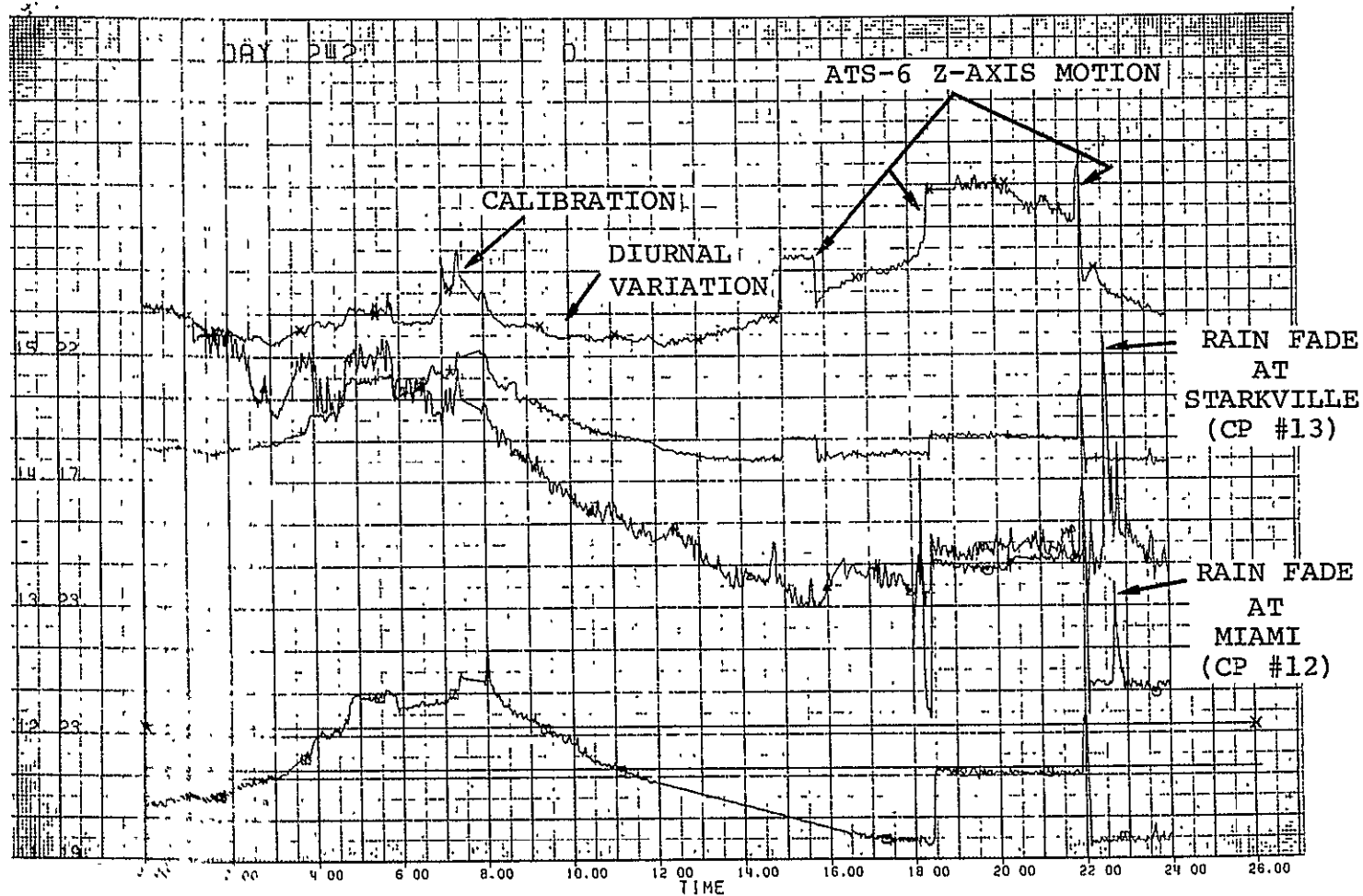


Figure 4-1. Raw Data for 1974, Day 242 for 4 Carriers

Received Power (dB)

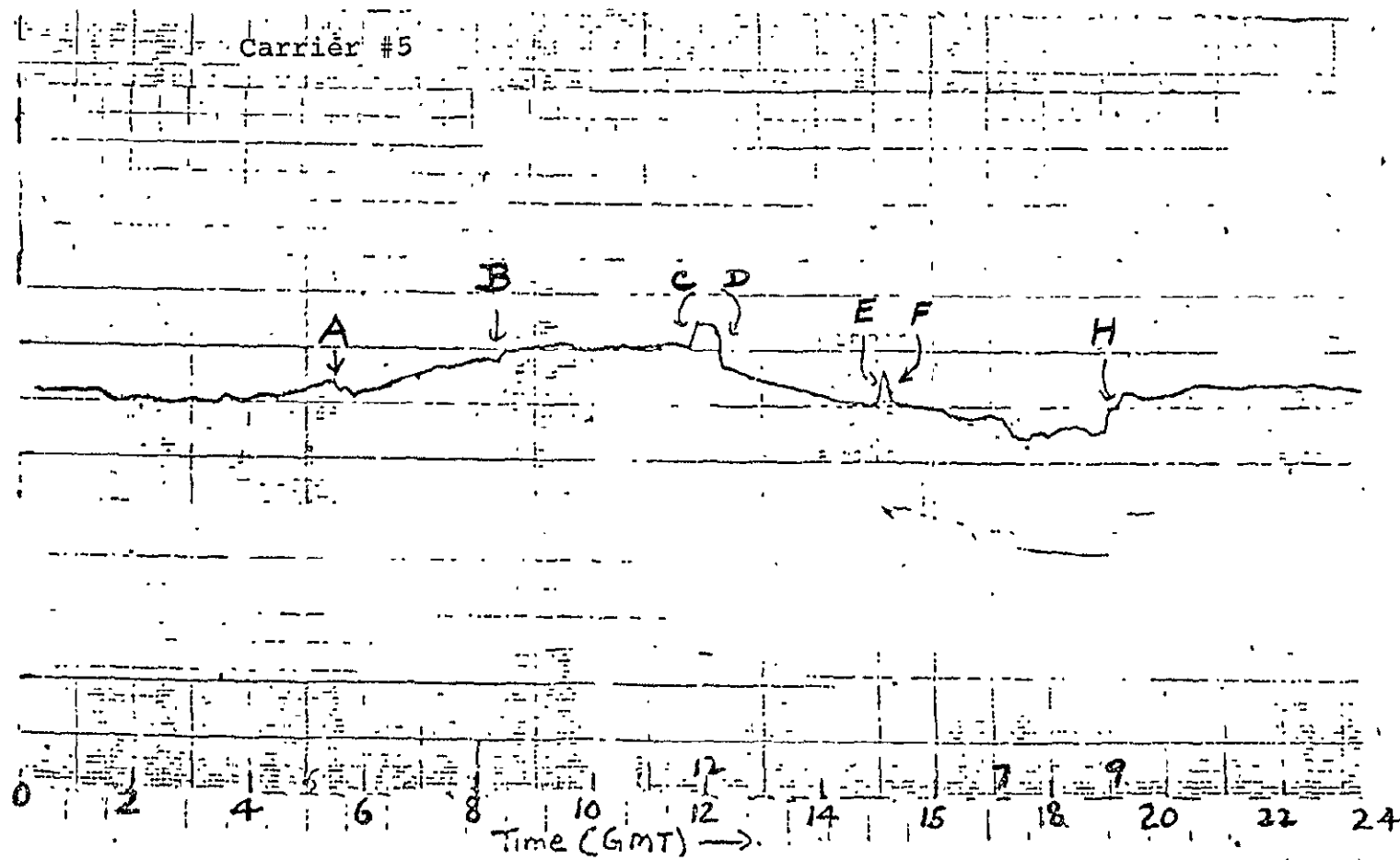


Figure 4-2. Received Carrier Power (I) for CP #5, Day 204

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experiments and programs using the ATS-6 required a variety of antenna boresight pointings that led to a host of attitude changes. Some of these attitudes were not compatible with the CPE, and data were lost completely. However, for many pointings, the attitude changes resulted in changes in ATS-6 CPE antenna gains relative to the GTT's and the receiver and DAQS, and consequent variations of signal levels. Such effects are marked in Figure 4-2 as events A through H, each appearing as an arbitrary signal level shift that must not be confused with rain-induced signal level changes. If the gain changes did not occur at too rapid a rate, and if the various GTTs and/or the receive and DAQS site remained inside the main beam, then the ephemeris data and telemetry tapes provided a means for correcting the gain changes produced by these attitude changes and thus providing the necessary correction of the signal level data base.

Because the transponder gain was a function of temperature (recall Figure 3-7) the transponder output power and TWTA temperature were monitored and telemetered back to NASA so that this information could later be used in correcting the signal level data base. This telemetry data along with attitude and ephemeris data for every 48 seconds were put on daily tapes provided by the NASA/GSFC Computer Center to COMSAT Labs several months later. The data tapes from the receive and DAQS site and the NASA tapes were read into the COMSAT Labs IBM 360/65 computer, and processed by a corrections program that resulted in the production of a first-pass data file from which it was originally thought that the final statistics could be derived. It turned out that this was not so, and that a much greater data correction effort had to be performed to improve the quality of the data base to its present level.

An example of the unexpected problems encountered follows. In the course of developing individual correction factors for the diurnal variations described above, the pointing parameters of the ATS-6 CPE receive antennas which were provided by NASA were used. It proved to be impossible to develop a consistent set of diurnal correction factors and also consistent corrections for attitude changes. It was shown that if it was assumed that the measured variations were correct, and that the ATS-6 CPE 13/18-GHz spacecraft receive antenna boresight axis was in error, this matter could be resolved. Figure 4-3 shows antenna pointing provided by NASA and Figure 4-4 shows the antenna pointing deduced from the measured data, in spacecraft-centered coordinates (where  $A_s$  is the spacecraft main antenna boresight axis,  $X_s$  is the in-plane orbit tangent, and  $Z_s^a$  is the CPE 13/18-GHz pointing axis). The deduced pointings were verified experimentally to within  $0.02^\circ$  subsequently by sweeping the spacecraft boresight through the beam of the NASA earth station at Rosman, N.C. and analyzing the resultant data. (Referenced to the spacecraft north-south axis, the given coordinates were  $2.9^\circ\text{E}$  and  $0.0^\circ\text{N}$ , the deduced coordinates were  $2.98^\circ\text{E}$ ,  $1^\circ\text{N}$ .)

The approach used was to develop a program which predicted the gain changes resulting from the satellite motion, attitude or temperature state, and then to subtract the predictions from the data collected. A sample of measured data taken from the Tampa 13-GHz carrier (CP#1) is compared to the predicted signal variations under clear sky conditions in Figure 4-5. It can be seen that the differences are less than 0.5 dB. Figure 4-6 shows the plots of four corrected 18-GHz carriers for a full day. Corrections which were applied included the previously mentioned corrections for diurnal variation, satellite attitude changes, temperature-induced transponder gain changes, corrections for attenuation due to the Andover radome

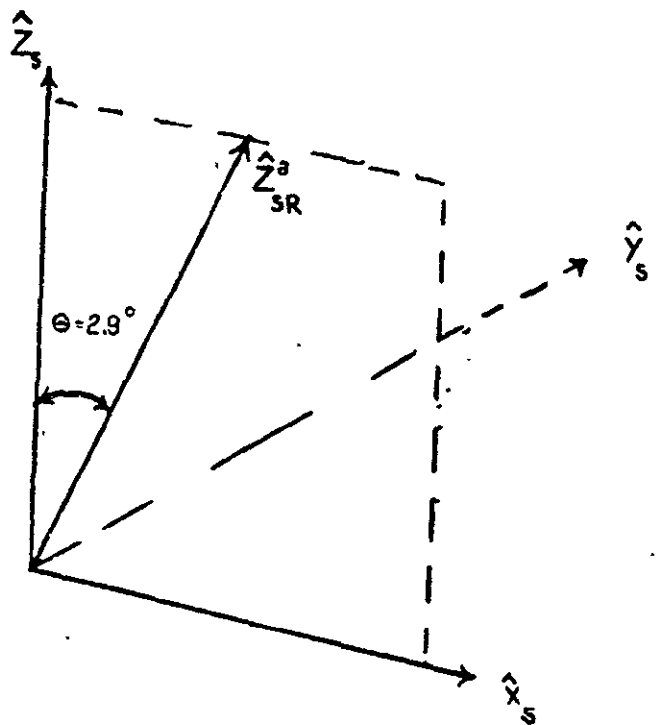


Figure 4-3. NASA - Provided Antenna Boresight Geometry

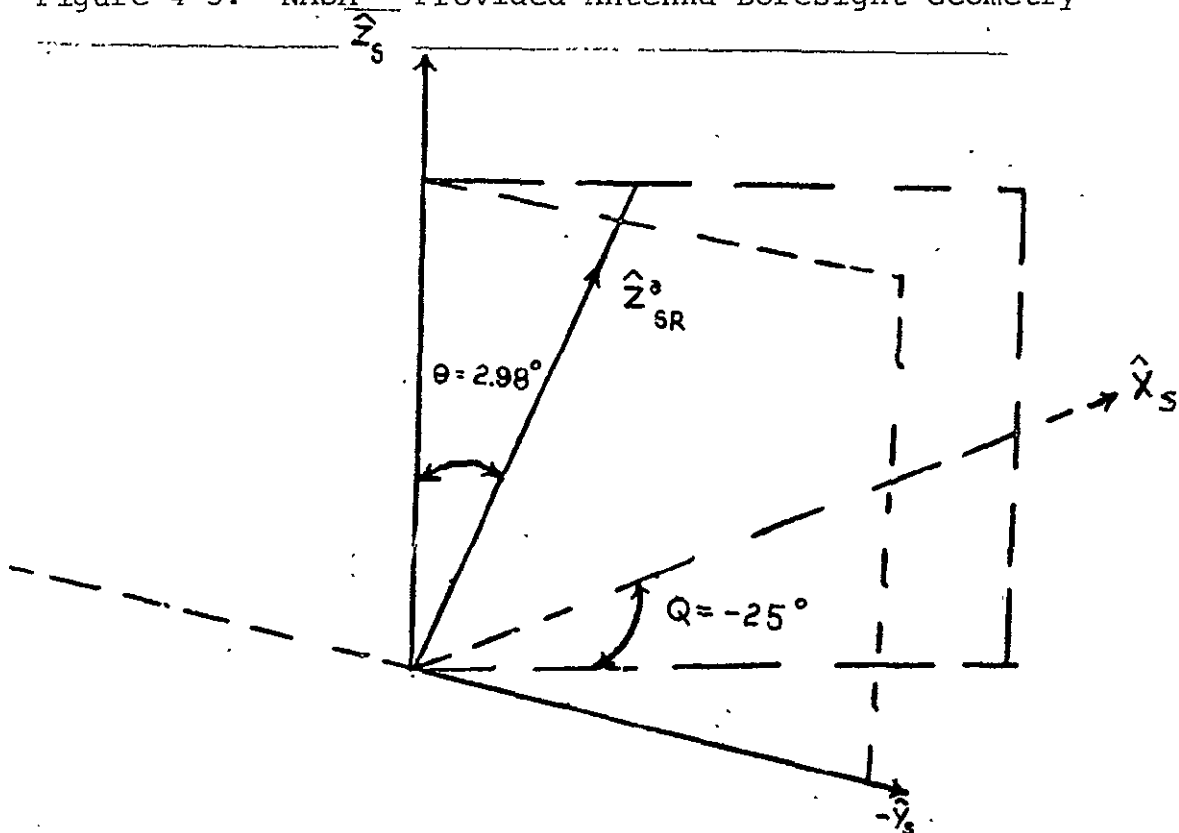


Figure 4-4. Deduced Antenna Boresight Geometry

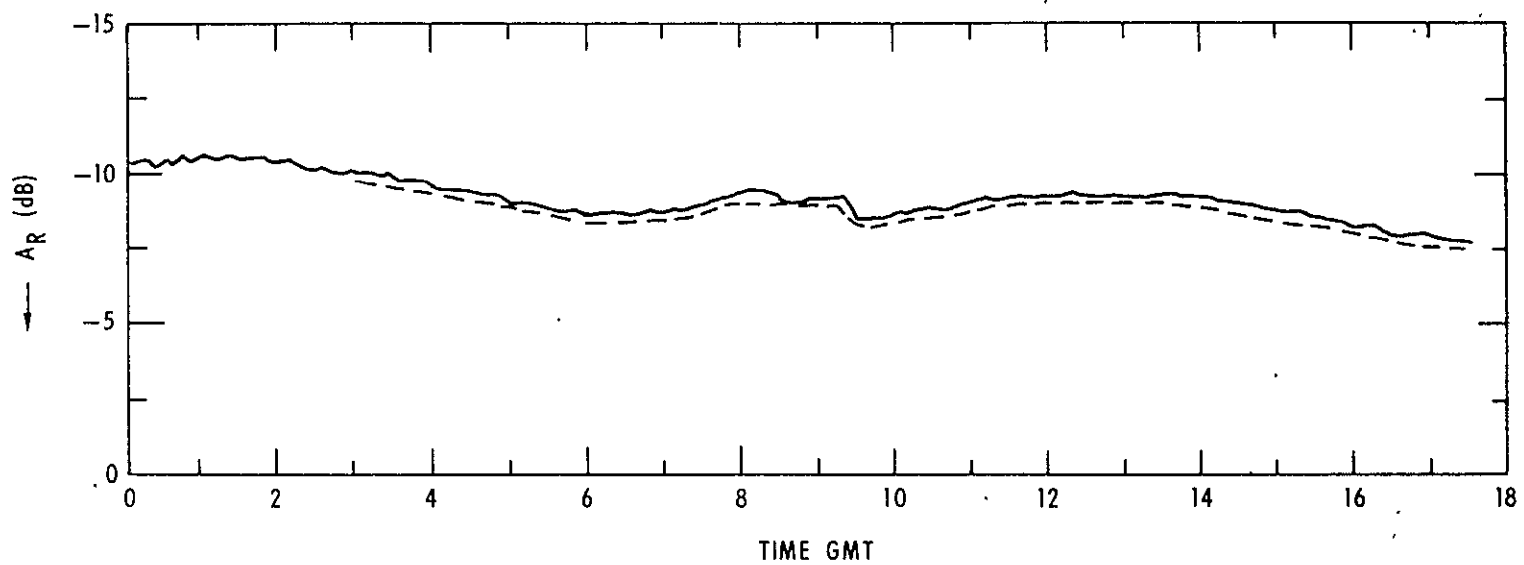


Figure 4-5. C.P. #1 Received Power, Showing Actual (solid) and Predicted (dashed) Variation Due to Satellite Motion

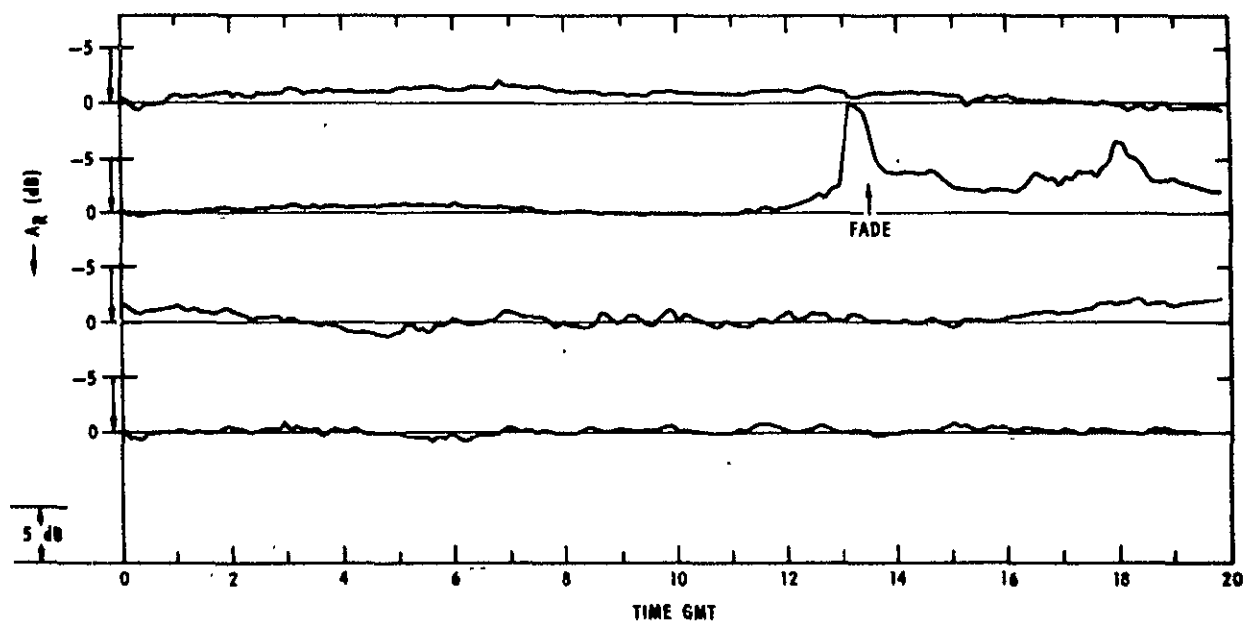


Figure 4-6. Typical Corrected Signal Data Plots for 24-hr Period

(when it got wet), deletions of data originating outside the 6-dB contours of the ATS-6 CPE 13- and 18-GHz receive antenna, and other corrections detailed in reference 5. There was a lengthy fade in the carrier second from the top, with a peak value slightly over 10 dB. The 18-GHz carriers tended to be noisier than the 13-GHz carriers. Also, there is some obvious residual diurnal variation in the top and third from the top carrier traces ( $\pm 0.5$  dB and  $\pm 0.75$  dB, respectively).

When all this was done, there still remained a small but significant amount of error in the first-pass data base. It should be noted that the percent-of-time of interest ranges from 0.005% of the time to about 0.5% of the time. A day contains 24 hours, or 1440 minutes, or 86,400 seconds. The range of interest covers 4.3 seconds to 430 seconds per day. It is evident that very small amounts of erroneous data or very minor erroneous corrections each day could cause significant percent-of-time errors in the data base. The potential for such errors existed. For example, telemetry data was available only every 48 seconds. In this length of time, a significant slewing of the spacecraft attitude could and often did take place. There were other problems, trivial in any other context, but not in a context where the percent-of-time of interest is 0.01%. Thus it turned out that the main result of the first-pass data reduction processing was to prepare the data for visual-processing data reduction steps whose purpose was to eliminate the remaining erroneous data. A sample of first-pass data is shown in Figure 4-7 with visual-processing band markings indicated. The corrections were encoded and entered into the corrections program. The output is shown in Figure 4-8. The data base that was obtained from this type of processing was analyzed using the data analysis



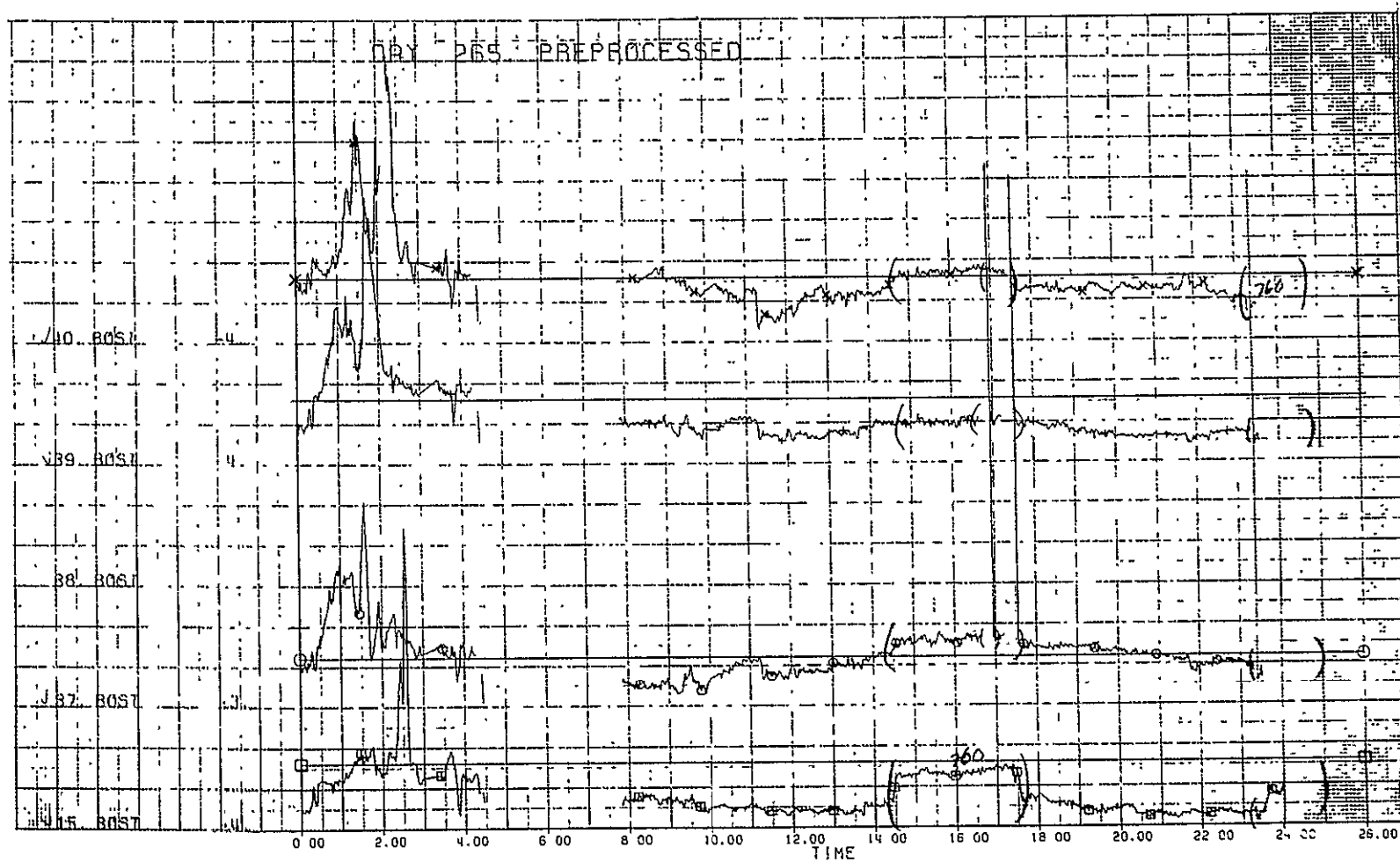


Figure 4-7. Day 265, Preprocessed Data

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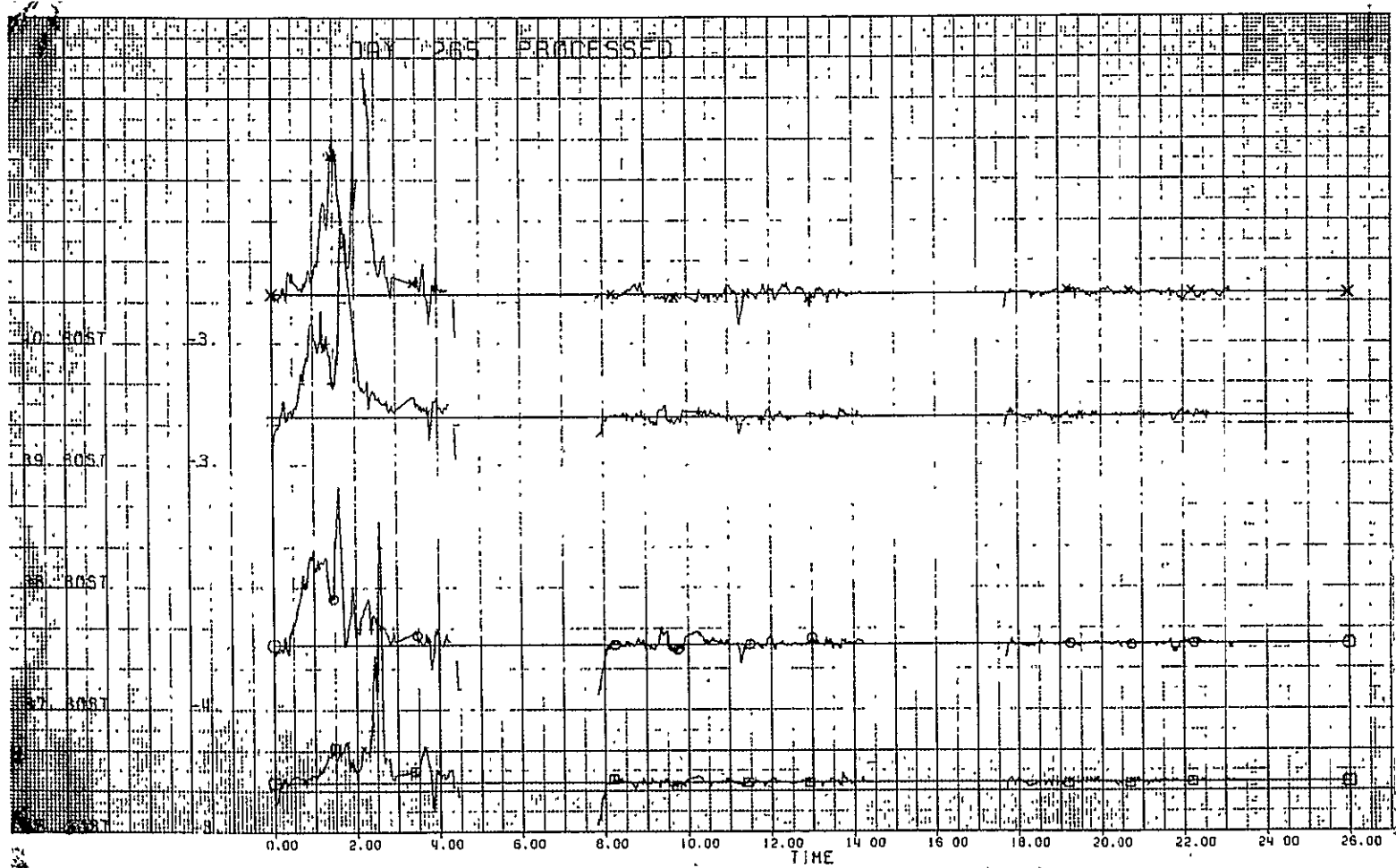


Figure 4-8. Day 265, Processed Data

programs and the results appear to be acceptable from an attenuation level of about 1.5 dB at 13 GHz and 2 dB at 18 GHz at low attenuation to a percent-of-time exceeded value of about 0.005% at high attenuations.

## 5. DATA ANALYSIS

### 5.1 GENERAL

The data analysis output was prepared in the form of plots and tables of attenuation and rain statistics for the dual-frequency sites and for the diversity sites. For the complete program, this included plots for quarters\* and the duration of the experiment and tables for the months, quarters and the duration of the experiment. The complete set of plots and tables are presented in the Data Analysis Report: Part II [6]. In this section, each type of plot and table is discussed, using as examples the plots and tables presenting the data for the duration of the experiment for the dual-frequency site at Fayetteville, N.C. and for the diversity sites near Boston, Mass.

The dual-frequency station (station #13) at Fayetteville radiated 25-W signals that were processed by CPs #4 (13-GHz) and #21 (18-GHz), and is designated in some of the tables as FAYV. The four Boston area stations included dual-frequency station #2 at Cambridge, Mass., designated B-C in some tables, and radiated 25-W signals that were processed by CPs #15 and #38. The single-frequency 7-W Boston diversity stations were station #17 at Waltham, Mass., processed by CP #40; station #18 at Sudbury, Mass., processed by CP #39; and station #19 at Marlboro, Mass., processed by CP #37.

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\* Quarters were defined by NASA/GSFC as follows:

First quarter: 1974 days 202 to 273  
Second quarter: 1974 days 274 to 365  
Third quarter: 1975 days 1 to 59  
Fourth quarter: 1975 days 60 to 137

For the Fayetteville 13- and 18-GHz carriers, individually, cumulative fading statistics are presented in graphic and tabular form, fade duration statistics are tabulated, and the diurnal variation of fades is tabulated and presented in histogram form. In addition, the joint cumulative fading statistics of 1 to 10 sites at 13 GHz and at 18 GHz are presented in graphical and tabular form. Also, for the joint on times (the times when both 13- and 18-GHz carriers were on and processible data was collected) the 13- and 18-GHz cumulative fading statistics and 13/18-GHz fade depth correlation are given in graphs and tables.

For the Boston diversity site carriers, cumulative fading statistics are presented in graphical and tabular form for the four 18-GHz carriers (and the 13-GHz carrier at the dual-frequency site). The diversity pair cumulative fading statistics are presented in similar form for each of the six pairs of 18-GHz carriers. Each of the six sets includes the joint on time cumulative attenuation statistics for the individual 18-GHz carriers, in each pair, and the diversity cumulative attenuation statistics of that pair (i.e., for the better of either at every instant). The diversity statistics are compared graphically and then the diversity gain is plotted and tabulated for each diversity pair.

Rain data collection statistics are tabulated for the GTT sites, and coincidence times with the carriers are also given. The cumulative rain rate statistics are plotted and tabulated for the Fayetteville and Boston GTT sites for total rain collection time, and joint on time with their respective carriers. Extrapolated cumulative attenuation and rain rate statistics are also given.

## 5.2 DUAL-FREQUENCY SITE DATA ANALYSIS

Carriers at both 13 and 18 GHz were transmitted from the 15 sites listed in Section 2 and were collected by the DAQS. Additionally, point rain data was collected using a rain gauge which was located on the roof of each GTT. These data, after correction, reduction and storage in computer data files, were analyzed to produce: statistical presentations of rain-induced attenuation of each carrier, joint attenuation of the 13- and 18-GHz carriers transmitted from an individual GTT, rain at each site, and joint attenuation at widely-spaced sites.

### 5.2.1 CUMULATIVE ATTENUATION

For purposes of quantitatively considering the effects of rain-induced attenuation on a communications link, it is necessary to know how much of the time a certain fade level to be equaled or exceeded can be expected, since system performance is so quantified. The attenuation contributes to system performance by reducing signal strength and increasing noise levels in the receiver. Thus, for example, from Figure 5-1, it can be seen that the 12-dB fade level was equaled or exceeded approximately 0.016 percent-of-the time at 13 GHz for a path between the Fayetteville, N.C. GTT site and the ATS-6. Alternatively, the exceedance level for 0.01 percent-of-the time was approximately 14 dB at 13 GHz on this path. The exceedance level for 0.02 percent-of-the time was about 10.8 dB, i.e., doubling the percent-of-the time exceeded saves about 3 dB in margin. On the other hand, halving the percent-of-time exceeded to 0.005 percent increases the exceedance level to about 20.5 dB, i.e., the margin



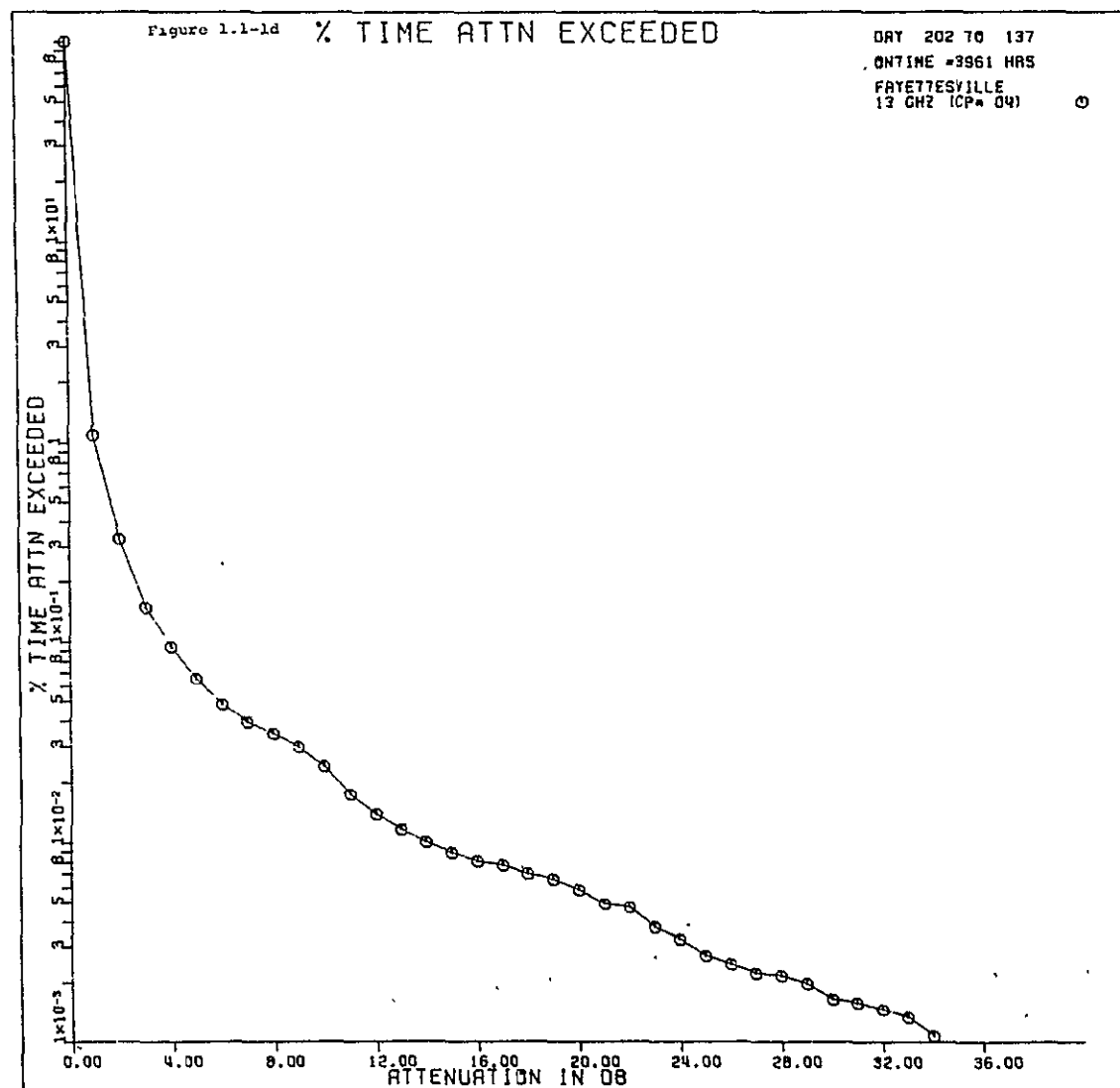


Figure 5-1. Fayetteville, 13 GHz (CP #04), Percent-of-Time Attenuation Exceeded

requirements increase sharply as percent-of-time decreases. Note that this cumulative attenuation curve has a distinct bend between about 3 and 7 dB, near about 0.1 percent-of-the time. This bend to a more-rapid increase in attenuation as a function of decreasing percent-of-time parallels a similar bend in the rain-rate exceedance curves, and is discussed below with the data.

It may be noted on the legend of the figure that the data collection period covered radio days 202 (1974) to 137 (1975), and that during this period, 3961 hours of reducible data were collected from carrier processor #04 (recall from Table 3-3 that carrier processor #04 was assigned to collect the Fayetteville 13-GHz signals). The 3961 hours of on time does not reflect the total transmit time of the 13-GHz carrier. All data has been deleted for times when the ATS-6 boresight axis pointing precluded any CPE data being collected, times when the pointing precluded Fayetteville data being collected, times when the satellite attitude was changing too fast for correction to be applied, times when the receive and DAQS was being calibrated, and times when several other lesser sources of deletion occurred. Therefore, on time should be understood to mean hours of data collected that were applicable to the processing used in a particular data base analysis.

This data is listed in Table 5-1, for all the 13-GHz carriers, with the Fayetteville 13-GHz carrier data being listed in the column headed FAYV. Other abbreviations are TMPA for Tampa, N.OR for New Orleans, NSHV for Nashville, WASH for Washington, D.C., PHIL for Philadelphia, ANDV for Andover, DETR for Detroit, W.IS for Wallops Island, MIAM for Miami, MSU for Mississippi State University at Starkville, OSU for Ohio State University at Columbus, and B-C for Boston-Cambridge.

### 5.2.2 FADE DURATION

The attenuation data base was analyzed to extract information on fade duration. Tables 5-2 through 5-7 provide a tabulation of the duration of fades at 13 GHz at levels equal to or exceeding 3, 6, 10, 15, 20 and 25 dB. For example, there is one fade at FAYV of depth  $\geq 3$  dB that lasted between 41 and 45 minutes (Table 5-2); this fade on the  $\geq 6$  dB table (Table 5-3), lasted between 36 and 40 minutes; and at  $\geq 10$  dB (Table 5-4), 21 to 25 minutes, etc. There were no fades of duration longer than one minute at a level  $\geq 20$  dB, 1 at  $\geq 15$  dB, 15 at  $\geq 6$  dB, and 61 at  $\geq 3$  dB.

### 5.2.3 FADE OCCURRENCE

The data base was also analyzed to see if there was a diurnal pattern to such fades; the hourly fade distribution is presented in Figure 5-2. Because of the gaps in the data base and due to the relatively short duration of the experiment (300 days total), the data was prepared by sorting the fade data according to hour-of-the day (GMT), and dividing the total number of minutes of fade at the various levels by the total days during which data was collected. Thus the worst hour at Fayetteville was 2300 to 2400 GMT (1800 to 1900 EST, or 6 p.m. to 7 p.m. in standard time). As shown, during this hour on the average there were 24 seconds of  $\geq 3$ -dB fades, 18 seconds of  $\geq 6$ -dB fades, and 12 seconds of  $\geq 10$ -dB fades. Table 5-8 gives the data that was collected for the Fayetteville 13-GHz carrier (and the Asheville and Nashville 13-GHz carriers). (Note, that the GMT hour from 1 to 24 is given at the top of the table, and the number of days that particular hour provided processible data is given at the bottom line for each carrier.)

Table 5-1. Percent-of-the-Time Attenuation Exceeded  
At Each 13-GHz Site

13 GHZ FREQ. BAND	% TIME ATTENUATION EXCEEDED AT EACH SITE														0 202 TO 75 137
DB	TNPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	OSU	B-C
1	0.85	2.72	1.78	1.09	1.09	2.18	2.47	1.57	7.10	0.37	0.67	0.91	3.90	0.50	0.56
2	0.37	1.18	0.76	0.33	0.39	1.80	1.33	1.05	5.75	0.26	0.38	0.52	2.68	0.16	0.26
3	0.18	0.11	0.37	0.15	0.25	1.61	0.25	0.43	3.52	0.18	0.21	0.37	1.81	0.08	0.15
4	0.14	0.07	0.27	0.05	0.19	1.56	0.10	0.21	2.02	0.14	0.14	0.30	1.28	0.05	0.10
5	0.11	0.05	0.24	0.07	0.14	1.53	0.07	0.12	1.09	0.11	0.10	0.24	0.92	0.03	0.07
6	0.10	0.04	0.21	0.05	0.11	1.52	0.05	0.07	0.59	0.09	0.06	0.17	0.62	0.02	0.05
7	0.08	0.03	0.19	0.04	0.08	1.51	0.04	0.05	0.35	0.07	0.04	0.14	0.37	0.02	0.03
8	0.07	0.02	0.17	0.03	0.06	1.49	0.03	0.03	0.22	0.05	0.03	0.13	0.20	0.01	0.03
9	0.07	0.02	0.15	0.03	0.05	1.49	0.03	0.03	0.15	0.04	0.02	0.11	0.11	0.01	0.02
10	0.06	0.02	0.14	0.02	0.03	1.48	0.02	0.02	0.11	0.03	0.02	0.10	0.07	0.01	0.02
11	0.05	0.01	0.13	0.02	0.02	1.48	0.02	0.01	0.09	0.03	0.02	0.09	0.05	0.01	0.01
12	0.05	0.01	0.11	0.01	0.01	1.48	0.02	0.01	0.08	0.02	0.01	0.08	0.04	0.01	0.01
13	0.04	0.01	0.08	0.01	0.01	1.48	0.01	0.01	0.06	0.02	0.01	0.08	0.03	0.01	0.01
14	0.04	0.01	0.06	0.01	0.01	1.48	0.01	0.00	0.05	0.02	0.01	0.07	0.03	0.01	0.00
15	0.03	0.01	0.06	0.01	0.01	1.48	0.01	0.00	0.04	0.01	0.01	0.06	0.02	0.01	0.00
16	0.03	0.01	0.05	0.01	0.01	1.36	0.01	0.00	0.03	0.01	0.01	0.06	0.02	0.01	0.00
17	0.03	0.01	0.05	0.01	0.01	1.26	0.01	0.00	0.02	0.01	0.01	0.06	0.02	0.00	0.00
18	0.02	0.01	0.04	0.01	0.01	1.21	0.00	0.00	0.02	0.01	0.01	0.05	0.02	0.00	0.00
19	0.02	0.01	0.04	0.01	0.01	1.20	0.00	0.00	0.01	0.01	0.01	0.05	0.02	0.00	0.00
20	0.02	0.01	0.03	0.01	0.01	1.15	0.00	0.00	0.01	0.01	0.01	0.05	0.01	0.00	0.00
21	0.02	0.01	0.03	0.00	0.01	0.87	0.00	0.00	0.01	0.01	0.00	0.04	0.01	0.00	0.00
22	0.02	0.01	0.03	0.00	0.01	0.63	0.00	0.00	0.01	0.01	0.00	0.04	0.01	0.00	0.00
23	0.02	0.01	0.03	0.00	0.00	0.17	0.00	0.00	0.01	0.01	0.00	0.04	0.01	0.00	0.00
24	0.01	0.00	0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.01	0.00	0.04	0.01	0.00	0.00
25	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00
26	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00
27	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00
28	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00
29	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00
30	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00
31	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00
32	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
33	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.00
HOURS ON	3374.	3173.	1676.	3961.	4451.	1251.	3666.	1761.	4317.	3504.	4303.	1805.	3339.	3426.	4112.

Table 5-2. Number of 3-dB Fades at Each 13-GHz Site

13 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE													0 202 TO 75 137	
3. DB LEVEL MINUTES		TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	OSU	B-C
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96 - 100		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
91 - 95		0	0	0	0	0	0	0	0	5	0	0	0	0	0	0
86 - 90		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
81 - 85		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
76 - 80		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
71 - 75		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
66 - 70		0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
61 - 65		0	0	0	0	0	0	0	0	5	0	0	0	3	0	0
56 - 60		0	0	0	0	0	0	0	1	4	0	0	0	2	0	0
51 - 55		0	0	0	0	0	0	0	0	3	0	1	0	1	0	0
46 - 50		0	0	0	0	0	0	0	0	6	0	1	1	1	0	0
41 - 45		0	0	0	1	0	0	0	0	8	0	0	0	2	0	0
36 - 40		0	0	1	0	0	0	1	0	9	1	1	0	1	0	0
31 - 35		0	0	0	0	0	0	1	0	9	0	0	0	3	0	2
26 - 30		0	0	0	0	2	0	1	0	9	0	1	0	4	0	1
21 - 25		0	0	1	0	2	0	2	0	9	0	0	1	4	0	1
16 - 20		3	0	0	2	1	0	1	5	18	2	2	0	9	1	3
11 - 15		5	1	0	1	2	1	2	8	27	6	2	7	16	2	6
6 - 10		7	7	5	10	11	8	10	8	33	9	4	7	55	3	3
1 - 5		32	30	25	47	50	11	60	33	165	42	50	46	344	24	30
0.60 - 1.00		39	24	31	23	27	7	44	26	141	27	39	45	247	13	14
0.10 - 0.50		284	188	1216	229	246	59	490	332	1265	137	216	219	1503	119	164

Table 5-3. Number of 6-dB Fades at Each 13-GHz Site

13 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE														0 202 TO		75 137	
6. DB LEVEL		TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	OSU	B-C			
MINUTES																			
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
96 -	100	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0			
91 -	95	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0			
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0			
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
61 -	65	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0			
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0			
46 -	50	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0			
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0			
36 -	40	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0			
31 -	35	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0			
26 -	30	0	0	0	0	0	0	1	0	3	0	1	0	2	0	0			
21 -	25	0	0	0	0	1	0	0	0	2	0	1	0	2	0	0			
16 -	20	1	0	1	0	0	0	1	0	4	1	1	0	5	0	0			
11 -	15	1	0	0	1	3	1	1	1	5	3	1	1	3	1	4			
6 -	10	7	2	2	3	2	0	2	6	6	5	3	4	8	0	7			
1 -	5	19	10	20	8	18	10	10	8	20	26	12	33	78	6	7			
0.60 -	1.00	23	3	23	5	9	1	3	1	5	15	11	37	43	6	2			
0.10 -	0.50	203	101	508	105	111	22	45	15	78	58	74	153	298	29	35			



Table 5-4. Number of 10-dB Fades at Each 13-GHz Site

13 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE												D 202 TO		75 137	
10. DB LEVEL MINUTES		TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAH	MSU	OSU	B-C	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 -	40	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
31 -	35	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 -	25	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	
16 -	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 -	15	1	0	0	0	2	1	2	0	1	0	0	0	1	0	0	
6 -	10	2	0	1	1	1	0	0	0	3	3	3	1	4	1	1	
1 -	5	9	6	17	5	9	0	5	5	9	12	7	25	18	3	7	
0.60 -	1.00	26	1	15	1	2	3	2	3	4	10	2	28	12	5	3	
0.10 -	0.50	179	86	322	92	91	18	41	16	67	51	62	141	118	25	31	

Table 5-5. Number of 15-dB Fades at Each 13-GHz Site

13 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE												0 202 TO	75 137	
15. DB LEVEL MINUTES		THPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	OSU	B-C
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66 -	70	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 -	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 -	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 -	15	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
6 -	10	1	0	0	0	1	0	1	0	1	0	0	0	1	0	0
1 -	5	5	1	7	1	2	0	2	1	5	2	1	2	6	2	1
0.60 -	1.00	19	3	19	3	3	0	2	0	5	7	4	31	11	2	2
0.10 -	0.50	162	76	143	73	80	16	28	13	60	48	51	136	91	25	27

Table 5-6. Number of 20-dB Fades at Each 13-GHz Site

13 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE														0 202 TO		75 137	
20. DB LEVEL MINUTES		TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIA M	MSU	OSU	B-C			
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
21 -	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
16 -	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
11 -	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
6 -	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
1 -	5	0	0	0	0	1	0	1	0	3	0	0	0	2	0	0			
0.60 -	1.00	5	2	17	3	1	0	1	0	5	4	3	18	11	0	1			
0.10 -	0.50	149	67	102	59	68	12	27	8	46	45	43	127	77	24	25			

Table 5-7. Number of 25-dB Fades at Each 13-GHz Site

13 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE													0 202 TO 75 137	
25. DB LEVEL MINUTES		TMPA	ATL	N.OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W.IS	MIAM	MSU	DSU	B-C
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96 - 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91 - 95		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86 - 90		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81 - 85		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76 - 80		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71 - 75		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66 - 70		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61 - 65		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 - 60		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51 - 55		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46 - 50		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 - 45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 - 40		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 - 35		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 - 30		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 - 25		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 - 20		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 - 15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 - 10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 - 5		1	0	0	0	0	0	0	0	1	0	0	0	2	0	0
0.60 - 1.00		0	0	3	0	0	0	0	0	3	0	0	1	2	0	0
0.10 - 0.50		114	39	94	25	39	9	17	4	35	33	24	118	59	15	20

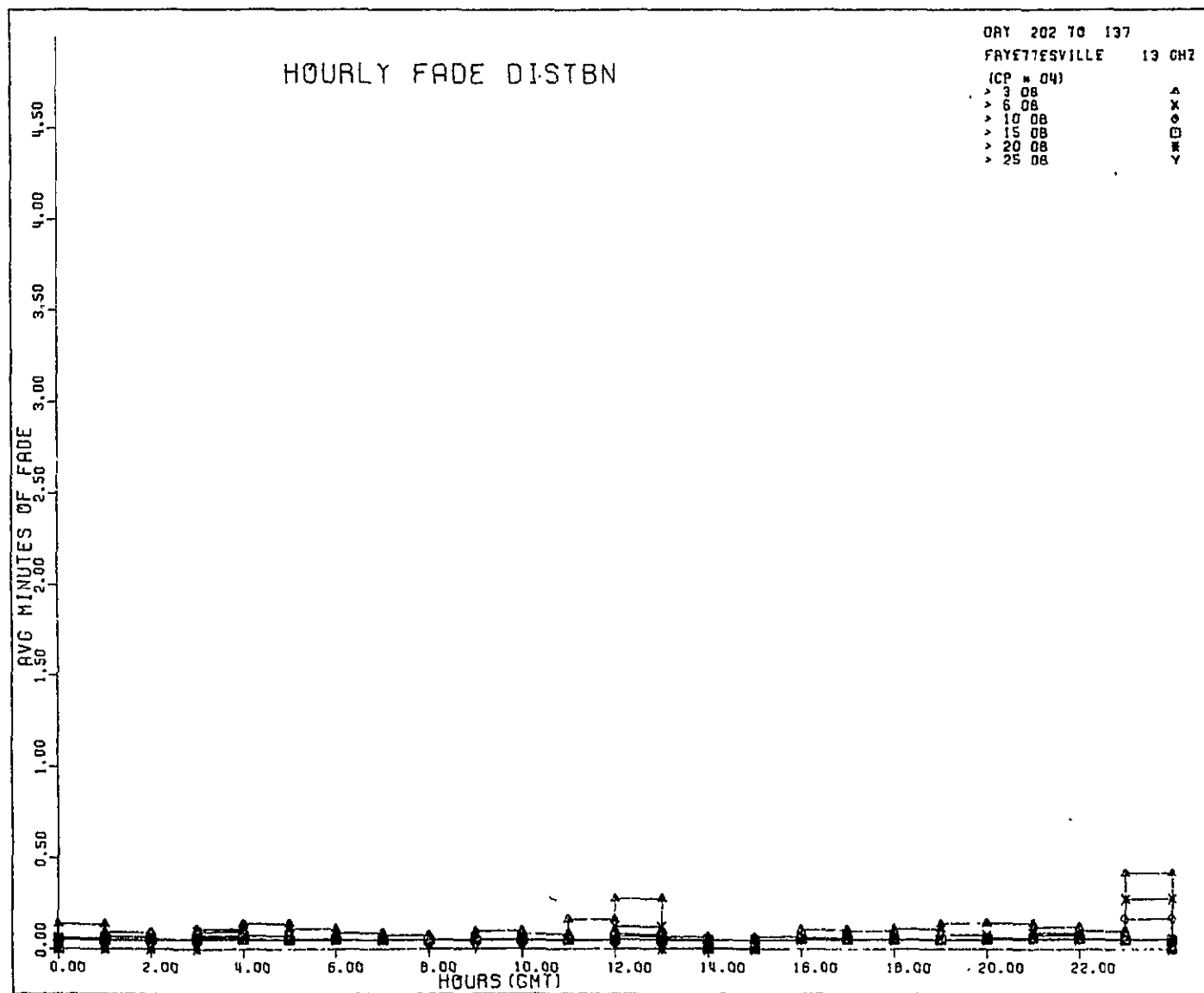


Figure 5-2. Fayetteville, 13-GHz Hourly Fade Distribution

Table 5-8. Hourly Distribution of Fade at 13 GHz

FADE DEPTH (DB)	DISTRIBUTION OF FADES OVER 24 HOUR PERIOD																							
	0 202 TO 75 137																							
	AVG. MINUTES OF FADE																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
13 GHZ FREQ. BAND FAYETTESVILLE																								
> 0	0.9	0.3	0.4	0.5	0.8	0.5	0.6	0.6	0.6	0.6	0.5	0.5	0.6	0.4	0.4	1.2	0.8	0.8	0.5	0.4	0.5	0.4	0.4	1.0
> 3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4
> 6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3
> 10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
> 15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 20	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 25	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NO. OF DAYS ON BY MONTH																								
	212	205	197	207	208	170	142	193	192	181	190	189	196	198	183	210	212	217	212	212	210	208	214	210
13 GHZ FREQ. BAND NASHVILLE																								
> 0	1.0	0.7	0.5	0.3	0.7	0.4	0.4	0.5	0.7	0.9	0.7	0.9	0.5	0.4	0.3	0.6	0.8	0.4	0.3	0.8	0.4	0.7	0.6	0.9
> 3	0.4	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.3	0.1	0.2
> 6	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.3	0.1	0.1	0.1	0.1	0.2	0.1	0.1
> 10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 20	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 25	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NO. OF DAYS ON BY MONTH																								
	243	217	224	234	234	196	164	215	212	201	202	210	216	222	207	232	234	234	229	236	233	235	239	232
13 GHZ FREQ. BAND NASHVILLE																								
> 0	1.6	1.1	2.0	2.1	1.8	0.9	0.6	1.9	0.9	1.2	0.4	0.3	1.1	1.0	0.9	0.2	0.7	0.1	0.4	1.2	1.1	1.3	1.6	2.5
> 3	1.2	1.0	1.9	1.9	1.7	0.5	0.1	1.6	0.7	0.8	0.1	0.0	0.3	0.2	0.3	0.0	0.1	0.0	0.3	1.1	1.0	1.1	1.5	2.3
> 6	1.1	1.7	1.6	1.9	1.6	0.5	0.1	1.6	0.7	0.8	0.1	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.2	1.1	1.0	1.0	1.4	2.2
> 10	1.0	1.0	1.5	1.9	1.6	0.5	0.1	1.6	0.7	0.8	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.2	1.1	1.0	1.0	1.4	2.2
> 15	1.0	1.0	1.5	1.9	1.6	0.5	0.1	1.6	0.7	0.8	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.2	1.1	1.0	0.9	1.4	2.2
> 20	1.0	1.0	1.5	1.9	1.5	0.5	0.1	1.6	0.7	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.2	1.4	1.9
> 25	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.1
NO. OF DAYS ON BY MONTH																								
	63	62	71	77	77	63	57	69	66	57	59	57	60	59	59	63	66	61	57	57	62	63	60	63

#### 5.2.4 JOINT FADING

In any satellite communications system serving land areas dominated by related and/or interacting widespread-weather systems, the potential for correlation between fades at various sites exists. Weather patterns such as a "Bermuda high" off the south-central Atlantic Coast in summer months often produces a flow of warm-moist air off the Gulf of Mexico and north and east across the Appalachian Mountain chain, often accompanied by rain. Thus, joint fading of widespread GTT sites, should be studied.

Figure 5-3 shows the cumulative statistics for joint fading, at 13 GHz, of at least 1 through 10 sites simultaneously. It can be seen that for 1 percent-of-the time there is at least one site in a fade of about 6 dB or more; for 0.1 percent-of-the time at least 2 sites are in fades of about 4 dB, and for 0.01 percent-of-the time, there are at least 4 sites in fades of about 2.5 dB. This data is presented in tabular form in Table 5-9. In this table the hours on indicates the total number of hours that the number of sites considered were simultaneously providing data that went into the data base of paragraph 5.2.1. Thus, there were 4661 hours during which there were at least 3 sites were simultaneously providing data that was processed.

Tables 5-10 through 5-15 provide fade duration statistics. It can be seen from Table 5-10 that there were 5 occasions when fade of at least 3 dB, which lasted between 1 and 5 minutes occurred simultaneously at at least 3 sites. There were 16 occasions when fades of at least 3 dB that endured 6 minutes or more occurred simultaneously at at least 2 sites. Similarly, in Table 5-12, it can be seen that there were 2 occasions when fades of at least 10 dB which lasted between 1 and 5 minutes occurred simultaneously at at least 2 sites.



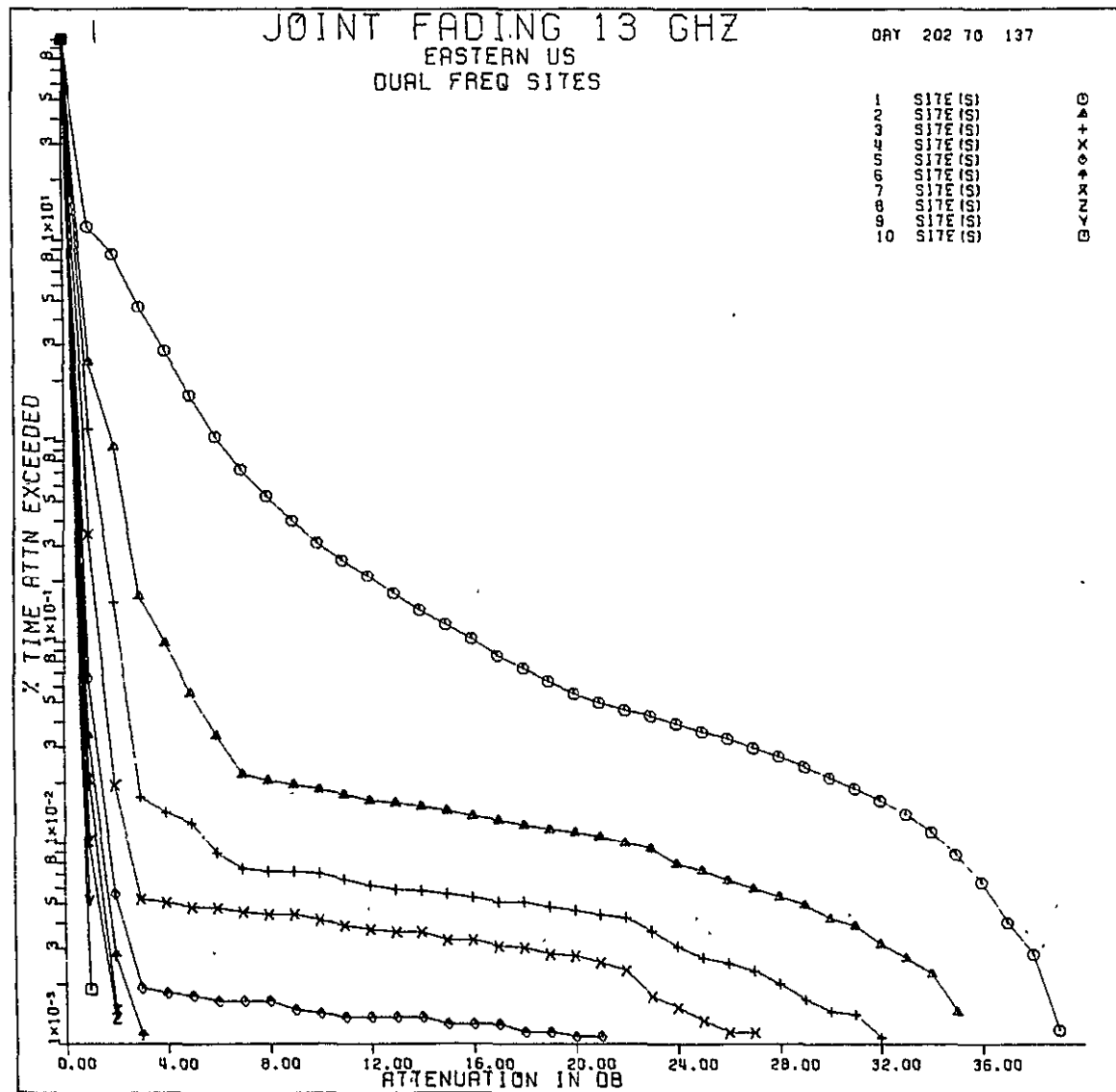


Figure 5-3. Joint Fading at 13 GHz at Dual-Frequency Sites

Table 5-9. Percent-of-Time Attenuation Exceeded Jointly at More Than One 13-GHz Site

13 GHz FREQ. BAND		% TIME ATTENUATION EXCEEDED JOINTLY AT MORE THAN ONE SITE															0 202 TO	75 137
DB	# SITES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
1	11.64	2.45	1.14	0.34	0.07	0.03	0.02	0.01	0.01	0.00	0.0	0.0	0.0	0.0	0.0	0.0		
2	8.49	0.93	0.16	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0		
3	4.65	0.17	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0		
4	2.80	0.10	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0		
5	1.69	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0		
6	1.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
7	0.73	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
8	0.54	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
9	0.40	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
10	0.31	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
11	0.26	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
12	0.21	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
13	0.17	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
14	0.14	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
15	0.12	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
16	0.10	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
17	0.09	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
18	0.07	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
19	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
20	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
21	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
22	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
23	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
24	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
25	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
26	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
27	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
28	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
29	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
30	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
31	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
32	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
33	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
34	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
35	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
36	0.01	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
37	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
38	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
39	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
40	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
HOURS ON	4695.	4680.	4661.	4631.	4601.	4544.	4388.	3916.	5078.	1469.	0.	0.	0.	0.	0.	0.		

Table 5-10. Number of Joint 3-dB Fades at More than One 13-GHz Site

13 GHZ FREQ. BAND			NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO	75 137
3. DB LEVEL		NUMBER OF SITES																
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
96 -	100	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
91 -	95	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
86 -	90	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
81 -	85	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
71 -	75	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
66 -	70	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
61 -	65	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
56 -	60	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
51 -	55	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
46 -	50	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
41 -	45	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
36 -	40	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
31 -	35	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
26 -	30	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
21 -	25	13	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
16 -	20	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
11 -	15	65	3	0	0	0	0	0	0	0	0	0	0	0	0	0		
6 -	10	124	11	1	0	0	0	0	0	0	0	0	0	0	0	0		
1 -	5	582	62	5	1	0	0	0	0	0	0	0	0	0	0	0		
0.60 -	1.00	400	44	3	2	0	0	0	0	0	0	0	0	0	0	0		
0.10 -	0.50	3863	467	105	50	26	18	6	4	3	3	0	0	0	0	0		
NUMBER OF SITES CONSIDERED =		10																

Table 5-11. Number of Joint 6-dB Fades at More Than One 13-GHz Site

13 GHZ FREQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO	75 137
6. DB LEVEL		NUMBER OF SITES															
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96 - 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91 - 95		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86 - 90		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81 - 85		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76 - 80		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71 - 75		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66 - 70		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61 - 65		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 - 60		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51 - 55		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46 - 50		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 - 45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 - 40		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 - 35		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 - 30		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 - 25		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 - 20		9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 - 15		18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 - 10		48	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 - 5		311	13	2	1	0	0	0	0	0	0	0	0	0	0	0	0
0.60 - 1.00		161	23	3	1	0	0	0	0	0	0	0	0	0	0	0	0
0.10 - 0.50		1433	232	85	48	24	16	5	4	0	0	0	0	0	0	0	0
NUMBER OF SITES CONSIDERED =		10															

13 GHZ FRQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO	75 137
10. DB LEVEL		NUMBER OF SITES															
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 -	25	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 -	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 -	15	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 -	10	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1 -	5	154	2	1	1	0	0	0	0	0	0	0	0	0	0	0	
0.60 -	1.00	177	11	1	0	0	0	0	0	0	0	0	0	0	0	0	
0.10 -	0.50	891	174	78	42	20	11	1	0	0	0	0	0	0	0	0	
NUMBER OF SITES CONSIDERED =		10															

Table 5-13. Number of Joint 15-dB Fades at More Than One 13-GHz Site

13 GHZ FREQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO	75 137
15. DB LEVEL		NUMBER OF SITES															
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 -	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 -	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 -	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 -	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1 -	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.60 -	1.00	95	8	1	1	0	0	0	0	0	0	0	0	0	0	0	
0.10 -	0.50	594	157	69	39	19	10	1	0	0	0	0	0	0	0	0	
NUMBER OF SITES CONSIDERED =		10															

Table 5-14. Number of Joint 20-dB Fades at More Than One 13-GHz Site

13 GHZ FREQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO	75 137
20. DB LEVEL		NUMBER OF SITES															
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 -	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 -	20	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 -	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 -	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1 -	5	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.60 -	1.00	46	1	1	1	0	0	0	0	0	0	0	0	0	0	0	
0.10 -	0.50	470	139	62	34	16	2	0	0	0	0	0	0	0	0	0	
NUMBER OF SITES CONSIDERED =		10															



Table 5-15. Number of Joint 25-dB Fades at More Than One 13-GHz Site

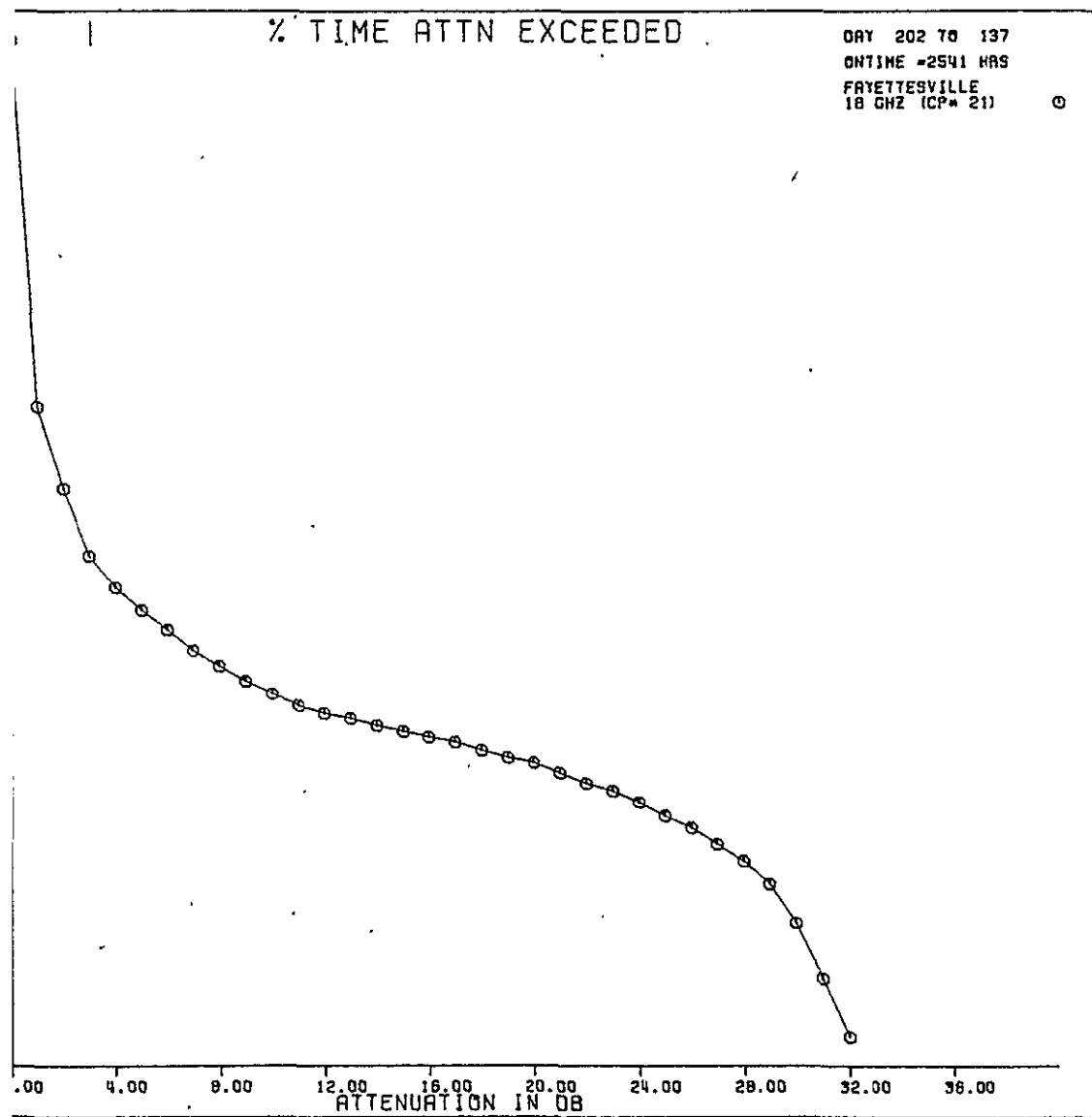
13 GHZ FREQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO	75 137
25. DB LEVEL		NUMBER OF SITES															
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 -	45	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 -	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 -	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 -	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 -	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1 -	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.60 -	1.00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.10 -	0.50	368	91	34	12	2	0	0	0	0	0	0	0	0	0	0	
NUMBER OF SITES CONSIDERED =		10															

#### 5.2.5 18-GHz DATA AT DUAL-FREQUENCY SITES

The same information which was discussed in paragraphs 5.2.1 through 5.2.4 for the 13-GHz carriers is available for the 18-GHz carriers on the slant paths from the dual-frequency sites. The cumulative attenuation statistics are plotted for the 18-GHz carrier originating at Fayetteville (Figure 5-4). It can be observed that attenuation exceedance levels are significantly higher for the same percent-of-time exceeded, as compared to the 13-GHz data shown in Figure 5-1. However, the on time for this carrier is only 2541 hours. (As it happened, during these times, the 13-GHz carrier was almost always providing processed data; these two sets of data will be compared in paragraph 5.2.6.) Table 5-16 gives a summary of 18-GHz carrier cumulative attenuation statistics.

Fade duration statistics are given in Tables 5-17 through 5-22. Fade distribution data are tabulated in Table 5-23 and plotted in Figure 5-5. The distribution through the day shown in this figure differs from that shown in Figure 5-2. Again this is due to different on times.

Joint fading statistics are shown in Figure 5-6 and given in Table 5-24. It is quite obvious from these statistics that serious fading at the high frequency must be expected and must be taken into account for joint fading of widely separated sites as well as single-site fading. That is, several links can be expected to be in a fade condition greater than 3 dB at the same time. It is shown in Figure 5-6 that fades  $\geq 3$  dB were encountered simultaneously on at least 4 slant paths (more than half the paths considered) for more than 0.01 percent-of-the time. Thus for 0.01 percent-of-the time, in the eastern U.S.A., at 18-GHz it can be expected to have about half of the paths in



-4. Fayetteville, 18 GHz, Percent-of-Time Attenuation Exceeded

Table 5-16. Percent-of-Time Attenuation Exceeded at Each 18-GHz Site

18 GHZ FREQ. BAND	% TIME ATTENUATION EXCEEDED AT EACH SITE															0 202 TO 75 137
DB	TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	OSU	B-C	
1	2.19	1.67	5.54	1.60	5.58	1.46	8.63	1.42	11.09	3.18	1.75	0.50	3.17	0.77	1.70	
2	1.06	0.70	4.44	0.64	4.63	0.45	7.52	0.51	9.04	2.25	0.85	0.27	2.44	0.29	0.85	
3	0.44	0.32	3.35	0.30	3.92	0.15	7.07	0.20	7.27	0.98	0.40	0.19	1.66	0.09	0.31	
4	0.29	0.24	2.27	0.21	3.49	0.09	6.94	0.17	6.15	0.27	0.26	0.16	0.90	0.05	0.19	
5	0.24	0.20	0.78	0.16	3.19	0.07	6.91	0.14	5.01	0.17	0.19	0.15	0.34	0.03	0.14	
6	0.21	0.16	0.36	0.13	2.79	0.07	6.90	0.14	3.89	0.14	0.15	0.14	0.22	0.02	0.10	
7	0.19	0.13	0.19	0.10	2.37	0.06	6.89	0.13	3.02	0.12	0.11	0.13	0.19	0.02	0.09	
8	0.18	0.12	0.18	0.09	1.73	0.06	6.89	0.13	2.08	0.11	0.08	0.13	0.17	0.02	0.07	
9	0.16	0.10	0.17	0.07	1.33	0.05	6.89	0.12	1.23	0.10	0.07	0.12	0.15	0.02	0.06	
10	0.15	0.09	0.16	0.06	0.95	0.05	6.88	0.12	0.56	0.09	0.06	0.12	0.14	0.02	0.05	
11	0.13	0.09	0.15	0.06	0.50	0.05	6.88	0.12	0.33	0.08	0.05	0.12	0.13	0.02	0.04	
12	0.12	0.08	0.14	0.05	0.13	0.04	6.88	0.12	0.21	0.07	0.05	0.12	0.12	0.02	0.03	
13	0.12	0.07	0.13	0.05	0.08	0.04	6.88	0.11	0.15	0.07	0.04	0.11	0.11	0.01	0.03	
14	0.11	0.07	0.12	0.04	0.06	0.04	6.80	0.11	0.12	0.06	0.03	0.10	0.10	0.01	0.03	
15	0.10	0.06	0.12	0.04	0.06	0.04	6.62	0.11	0.11	0.06	0.03	0.10	0.09	0.01	0.02	
16	0.10	0.06	0.10	0.04	0.05	0.03	6.33	0.11	0.09	0.05	0.03	0.10	0.08	0.01	0.02	
17	0.09	0.05	0.10	0.04	0.05	0.03	6.09	0.11	0.08	0.05	0.03	0.09	0.08	0.01	0.02	
18	0.09	0.04	0.08	0.03	0.05	0.03	5.87	0.10	0.07	0.04	0.02	0.09	0.07	0.01	0.02	
19	0.08	0.04	0.06	0.03	0.04	0.03	5.31	0.10	0.04	0.03	0.02	0.09	0.06	0.01	0.02	
20	0.09	0.04	0.05	0.03	0.04	0.03	4.25	0.10	0.02	0.03	0.02	0.09	0.06	0.01	0.02	
21	0.07	0.04	0.05	0.03	0.03	0.02	3.31	0.09	0.02	0.02	0.02	0.08	0.05	0.01	0.02	
22	0.07	0.03	0.04	0.02	0.03	0.02	2.27	0.06	0.02	0.02	0.01	0.08	0.05	0.01	0.01	
23	0.05	0.03	0.03	0.02	0.02	0.02	1.10	0.03	0.01	0.02	0.01	0.07	0.05	0.01	0.01	
24	0.05	0.03	0.03	0.02	0.02	0.02	0.42	0.02	0.01	0.02	0.01	0.07	0.04	0.01	0.01	
25	0.05	0.03	0.03	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.07	0.04	0.00	0.01	
26	0.05	0.03	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.03	0.00	0.01	
27	0.04	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.03	0.00	0.01	
28	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.03	0.00	0.01	
29	0.04	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.04	0.02	0.00	0.01	
30	0.03	0.02	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.04	0.02	0.00	0.01	
31	0.02	0.02	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.04	0.02	0.00	0.01	
32	0.02	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.01	0.00	0.01	
33	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.01	
34	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	
35	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	
36	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	
37	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	
38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	
39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
HOURS ON	1461.	1006.	1219.	2541.	1618.	2025.	1268.	1241.	2681.	2050.	3667.	87.	2981.	2584.	2730.	

Table 5-17. Number of 3-dB Fades at Each 18-GHz Site

18 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE												0 202 TO		75 137	
3. DB LEVEL MINUTES		TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	DSU	B-C	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 -	100	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	
91 -	95	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 -	85	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	
76 -	80	3	0	2	0	0	0	0	0	0	0	0	0	1	0	0	
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 -	70	0	0	1	0	0	0	0	1	4	0	0	0	1	0	0	
61 -	65	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	
56 -	60	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	
51 -	55	0	0	0	0	0	0	0	0	1	2	0	0	1	0	0	
46 -	50	0	0	1	0	0	0	0	0	5	0	1	0	3	0	0	
41 -	45	0	0	1	0	1	0	0	0	3	0	0	0	0	0	1	
36 -	40	3	0	0	0	0	0	0	0	6	0	0	0	3	0	0	
31 -	35	0	0	0	0	0	0	0	0	5	0	1	0	1	0	1	
26 -	30	0	0	1	0	1	0	0	0	12	1	1	0	2	0	0	
21 -	25	2	0	1	1	2	0	0	0	7	3	3	0	1	0	4	
16 -	20	1	0	1	1	2	0	1	0	13	4	2	0	8	0	0	
11 -	15	2	2	3	3	7	1	1	0	9	8	8	0	10	0	6	
6 -	10	9	8	11	14	4	3	4	5	26	6	15	0	23	5	13	
1 -	5	64	28	53	79	71	39	15	9	156	103	63	0	225	22	44	
0.60 -	1.00	42	28	55	56	54	36	24	10	156	76	98	5	161	12	26	
0.10 -	0.50	288	133	340	274	259	229	147	73	1552	483	907	25	768	166	264	

Table 5-18. Number of 6-dB Fades at Each 18-GHz Site

18 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE												0 202 TO 75 137		
6. DB LEVEL MINUTES		TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	OSU	B-C
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96 -	100	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86 -	90	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66 -	70	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 -	60	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
51 -	55	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
46 -	50	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 -	40	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
31 -	35	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0
26 -	30	0	0	1	0	0	0	0	0	3	1	0	0	0	0	0
21 -	25	0	0	1	0	0	0	0	0	2	0	0	0	1	0	1
16 -	20	2	0	1	1	0	0	0	0	4	2	2	0	0	0	1
11 -	15	0	0	1	0	0	0	0	0	3	1	3	0	2	0	2
6 -	10	4	4	2	3	5	0	0	2	6	4	5	0	9	0	5
1 -	5	16	16	15	45	21	17	3	4	22	17	27	0	79	4	19
0.60 -	1.00	26	17	25	40	21	25	2	0	8	10	17	4	60	8	5
0.10 -	0.50	169	89	153	178	91	167	47	39	75	89	184	18	252	112	91

Table 5-19. Number of 10-dB Fades at Each 18-GHz Site

18 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE												0 202 TO	75 137	
10. DB LEVEL MINUTES		TMPA	ATL	N.OP	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W.IS	MIAM	MSU	OSU	B-C
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76 -	80	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66 -	70	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
61 -	65	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 -	30	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
21 -	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 -	20	0	0	2	0	0	0	0	0	1	1	0	0	1	0	0
11 -	15	1	0	0	0	0	0	0	0	2	3	1	0	0	0	0
6 -	10	0	1	2	0	1	0	0	0	3	1	2	0	4	0	2
1 -	5	27	10	10	19	16	8	0	3	11	15	17	0	57	2	18
0.60 -	1.00	24	16	21	44	16	23	1	0	5	5	12	3	59	5	3
0.10 -	0.50	166	78	144	169	87	156	36	33	60	82	167	17	246	99	89



Table 5-20. Number of 15-dB Fades at Each 18-GHz Site

18 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE												0 202 TO	75 137	
15. DB LEVEL MINUTES		TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	OSU	B-C
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96 - 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91 - 95		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86 - 90		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
81 - 85		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76 - 80		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71 - 75		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66 - 70		0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
61 - 65		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 - 60		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51 - 55		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46 - 50		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 - 45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 - 40		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 - 35		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 - 30		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
21 - 25		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 - 20		0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
11 - 15		1	0	0	0	1	0	0	0	0	1	0	0	0	0	0
6 - 10		0	0	2	0	0	0	0	0	0	3	2	0	1	0	0
1 - 5		10	4	2	3	6	0	0	2	4	6	6	0	24	0	3
0.60 - 1.00		28	13	17	35	16	20	0	1	11	10	9	1	68	3	13
0.10 - 0.50		160	71	134	165	75	142	27	27	51	74	153	17	235	91	84

Table 5-21. Number of 20-dB Fades at Each 18-GHz Site

18 GHZ. FREQ. BAND		NUMBER OF FADES AT EACH SITE														0 202 TO 75 137	
20. DB LEVEL MINUTES		TMPA	ATL	N.OP	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W.IS	MIAM	MSU	OSU	B-C	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 -	65	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 -	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 -	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 -	15	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
6 -	10	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
1 -	5	1	0	3	1	4	0	0	1	4	3	2	0	8	0	0	
0.60 -	1.00	23	10	10	13	6	7	0	1	5	13	6	0	47	1	12	
0.10 -	0.50	150	60	110	164	77	134	18	22	50	68	133	17	229	77	74	

Table 5-22. Number of 25-dB Fades at Each 18-GHz Site

18 GHZ FREQ. BAND		NUMBER OF FADES AT EACH SITE														0 202 TO	75 137
25. DB LEVEL MINUTES		TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	OSU	B-C	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 - 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 - 95		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 - 90		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 - 85		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 - 90		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 - 75		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 - 70		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 - 65		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56 - 60		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 - 55		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46 - 50		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 - 45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 - 40		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31 - 35		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26 - 30		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 - 25		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 - 20		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 - 15		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
6 - 10		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1 - 5		0	0	0	0	3	0	0	1	2	1	0	0	0	0	0	
0.60 - 1.00		7	0	1	2	2	0	0	0	1	2	2	0	11	0	0	
0.10 - 0.50		127	51	84	126	64	90	5	15	38	58	91	13	222	44	64	

Table 5-23. Hourly Distribution of 18-GHz Fade

FADE DEPTH(CB)	DISTRIBUTION OF FADES OVER 24 HOUR PERIOD																							
	AVG. MINUTES OF FADE																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
18 GHZ FREQ, BAND FAYETTESVILLE																								
> 0	1.0	0.9	1.2	2.0	1.4	0.8	1.1	0.8	0.5	0.9	0.8	0.7	1.0	0.5	0.3	0.6	0.4	0.6	0.5	0.6	0.6	0.3	0.4	0.6
> 3	0.2	0.2	0.1	0.3	0.3	0.2	0.2	0.1	0.1	0.3	0.4	0.1	0.3	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2
> 6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
> 10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 20	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NO. OF DAYS ON BY HOUR																								
	165	155	139	146	150	134	111	135	118	103	94	93	108	120	124	163	170	148	135	143	129	129	164	171
18 GHZ FREQ, BAND ASHFVILLE																								
> 0	3.3	3.7	4.0	2.6	1.9	0.7	0.4	1.7	1.0	2.1	1.1	1.9	3.0	2.6	2.4	2.6	2.3	2.3	2.6	4.3	4.1	4.4	3.7	4.0
> 3	2.4	1.6	1.1	0.4	0.3	0.1	0.1	0.9	0.7	1.1	1.0	1.5	2.5	2.4	2.3	2.1	2.1	2.0	2.3	4.0	3.4	3.9	3.3	3.3
> 6	1.0	0.3	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.3	1.0	0.9	1.1	1.0	1.3	2.1	2.0	1.9	2.3	3.8	3.3	3.7	2.3	2.2
> 10	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.7	1.1	0.9	0.8	1.0	2.1	2.2	0.9	0.1	0.2
> 15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 20	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NO. OF DAYS ON BY HOUR																								
	97	92	92	93	94	81	69	86	78	69	66	70	78	80	77	92	94	84	88	100	93	86	96	89
18 GHZ FREQ, BAND NASHVILLE																								
> 0	0.7	1.1	1.2	1.3	1.0	1.2	0.9	1.1	0.8	0.7	0.6	0.6	1.3	1.4	0.4	0.4	0.3	0.6	0.5	0.5	0.6	0.3	0.3	0.5
> 3	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1
> 6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
> 10	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 15	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 20	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
> 25	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NO. OF DAYS ON BY HOUR																								
	129	117	106	112	121	108	93	105	98	81	67	67	80	89	97	120	127	119	113	117	118	118	130	129

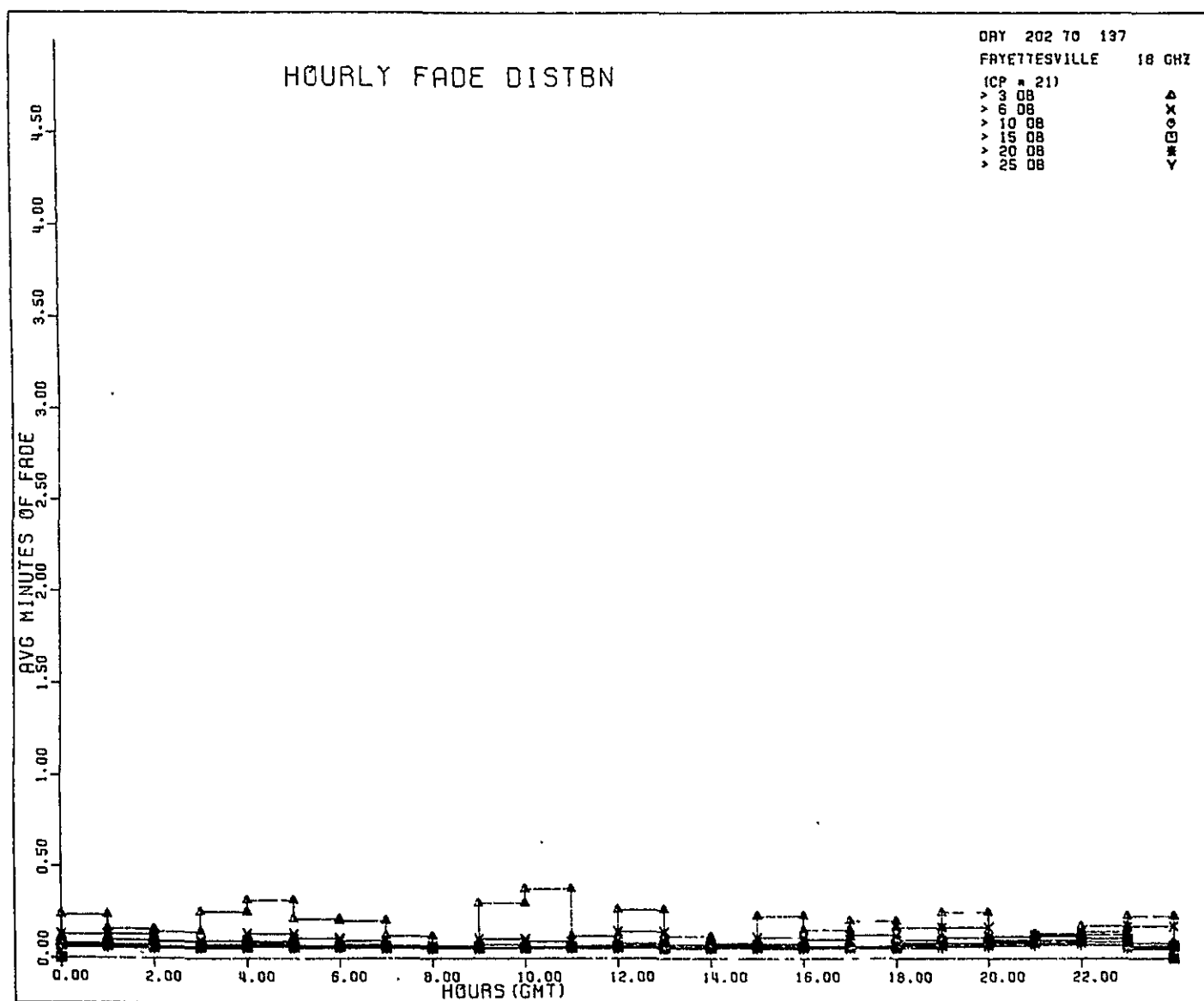


Figure 5-5. Fayetteville 18-GHz Hourly Distribution

Figure 5-6. Joint Fading at 18 GHz at Dual-Frequency Sites

Table 5-24. Percent-of-Time Attenuation Exceeded Jointly at More Than One 18-GHz Site

[illegible]



fades of more than 3 dB, based on this data sample. This could have a serious effect on system design. Table 5-24 recapitulates the data in tabular form. .

Tables 5-25 through 5-30 present the joint fade data in terms of duration. As shown, in the column for 1 or more sites in fades of 3 dB or more the 10 site system examined endured 213 fades of more than 1 minute.

#### 5.2.6 . JOINT 13/18-GHz STATISTICS

.It is important to establish the relationship between rain-induced attenuation at 13 and 18 GHz so that knowledge of frequency dependence of rain-induced fading between 10 and 20 GHz is improved, to permit more precise quantification of up- and down-link margins for systems that use links in this range of frequencies, and to establish the relationship between those margins if both up- and down-link frequencies lie between 10 and 20 GHz. Figure 5-7 shows the joint cumulative fade statistics for the Fayetteville to ATS-6 slant path for the Fayetteville carriers. Note that the joint on time is 2433 hours of processed data for each carrier. Comparing the data in Figure 5-7 to that in Figures 5-1 and 5-4 for the individual carriers, it is evident that there is little change in the 18-GHz cumulative statistics plot but there is a significant change in the 13-GHz plot for the higher levels of attenuation. The reason for this is due to the data base on times. The data base plotted in Figure 5-7 represents the time when both carriers were on. From Figure 5-4 it is observed that the joint on time is only slightly less than the individual carrier time for the 18-GHz curves (2433 hours as compared to 2584 hours); whereas, for the 13-GHz

Table 5-25. Number of Joint 3-dB Fades at More than One 18-GHz Site

18 GHZ FREQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO	75 137
3. DB LEVEL		NUMBER OF SITES															
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 -	100	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 -	95	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 -	90	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 -	85	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 -	80	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 -	75	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 -	70	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 -	65	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56 -	60	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 -	55	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	
46 -	50	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 -	45	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 -	40	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31 -	35	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26 -	30	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 -	25	10	2	1	0	0	0	0	0	0	0	0	0	0	0	0	
16 -	20	14	3	0	1	0	0	0	0	0	0	0	0	0	0	0	
11 -	15	12	5	2	0	0	0	0	0	0	0	0	0	0	0	0	
6 -	10	24	7	6	1	0	0	0	0	0	0	0	0	0	0	0	
1 -	5	113	36	20	4	0	0	0	0	0	0	0	0	0	0	0	
0.60 -	1.00	46	36	14	5	0	0	0	0	0	0	0	0	0	0	0	
0.10 -	0.50	178	188	91	33	8	4	0	0	0	0	0	0	0	0	0	
NUMBER OF SITES CONSIDERED =		6															

NUMBER OF SITES CONSIDERED = 6

22

22

Table 5-26. Number of 6-dB Fades at More Than One 18-GHz Site

18-GHZ FREQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO 75 137	
6. DB LEVEL MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 - 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 - 95		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 - 90		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 - 85		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 - 80		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 - 75		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 - 70		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 - 65		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56 - 60		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 - 55		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46 - 50		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 - 45		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 - 40		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31 - 35		6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26 - 30		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 - 25		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 - 20		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 - 15		5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 - 10		17	2	0	0	0	0	0	0	0	0	0	0	0	0	0	
1 - 5		86	33	1	0	0	0	0	0	0	0	0	0	0	0	0	
0.60 - 1.00		50	30	5	1	0	0	0	0	0	0	0	0	0	0	0	
0.10 - 0.50		145	160	60	29	7	3	0	0	0	0	0	0	0	0	0	
NUMBER OF SITES CONSIDERED =		6															

Table 5-28. Number of Joint 15-dB Fades at More Than One 18-GHz Site

18 GHZ FREQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO	75 137
15. DB LEVEL		NUMBER OF SITES															
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
96 - 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
91 - 95		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
86 - 90		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
81 - 85		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
76 - 80		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
71 - 75		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
66 - 70		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
61 - 65		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
56 - 60		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
51 - 55		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
46 - 50		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41 - 45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36 - 40		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31 - 35		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26 - 30		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21 - 25		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16 - 20		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11 - 15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6 - 10		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1 - 5		80	7	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.60 - 1.00		45	12	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.10 - 0.50		146	115	34	17	1	0	0	0	0	0	0	0	0	0	0	
NUMBER OF SITES CONSIDERED =		6															

Table 5-29. Number of Joint 20-dB Fades at More Than One 18-GHz Site

18 GHZ FREQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE											0 202 TO		75 137	
20. DB LEVEL		NUMBER OF SITES														
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 -	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 -	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 -	15	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 -	10	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 -	5	49	2	0	0	0	0	0	0	0	0	0	0	0	0	0
0.60 -	1.00	47	7	0	0	0	0	0	0	0	0	0	0	0	0	0
0.10 -	0.50	138	101	29	13	0	0	0	0	0	0	0	0	0	0	0
NUMBER OF SITES CONSIDERED =		6														

Table 5-30. Number of Joint 25-dB Fades at More Than One 18-GHz Site

18 GHZ FREQ. BAND		NUMBER OF JOINT FADES AT MORE THAN ONE SITE														0 202 TO		75 137	
25. DB LEVEL		NUMBER OF SITES																	
MINUTES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
> 100		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
96 -	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
91 -	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
86 -	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
81 -	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
76 -	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
71 -	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
66 -	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
61 -	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
56 -	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
51 -	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
46 -	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
41 -	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
36 -	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
31 -	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
26 -	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
21 -	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
16 -	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
11 -	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
6 -	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
1 -	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0.60 -	1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
0.10 -	0.50	107	63	11	3	0	0	0	0	0	0	0	0	0	0	0			
NUMBER OF SITES CONSIDERED =		6																	

NUMBER OF SITES CONSIDERED = 6

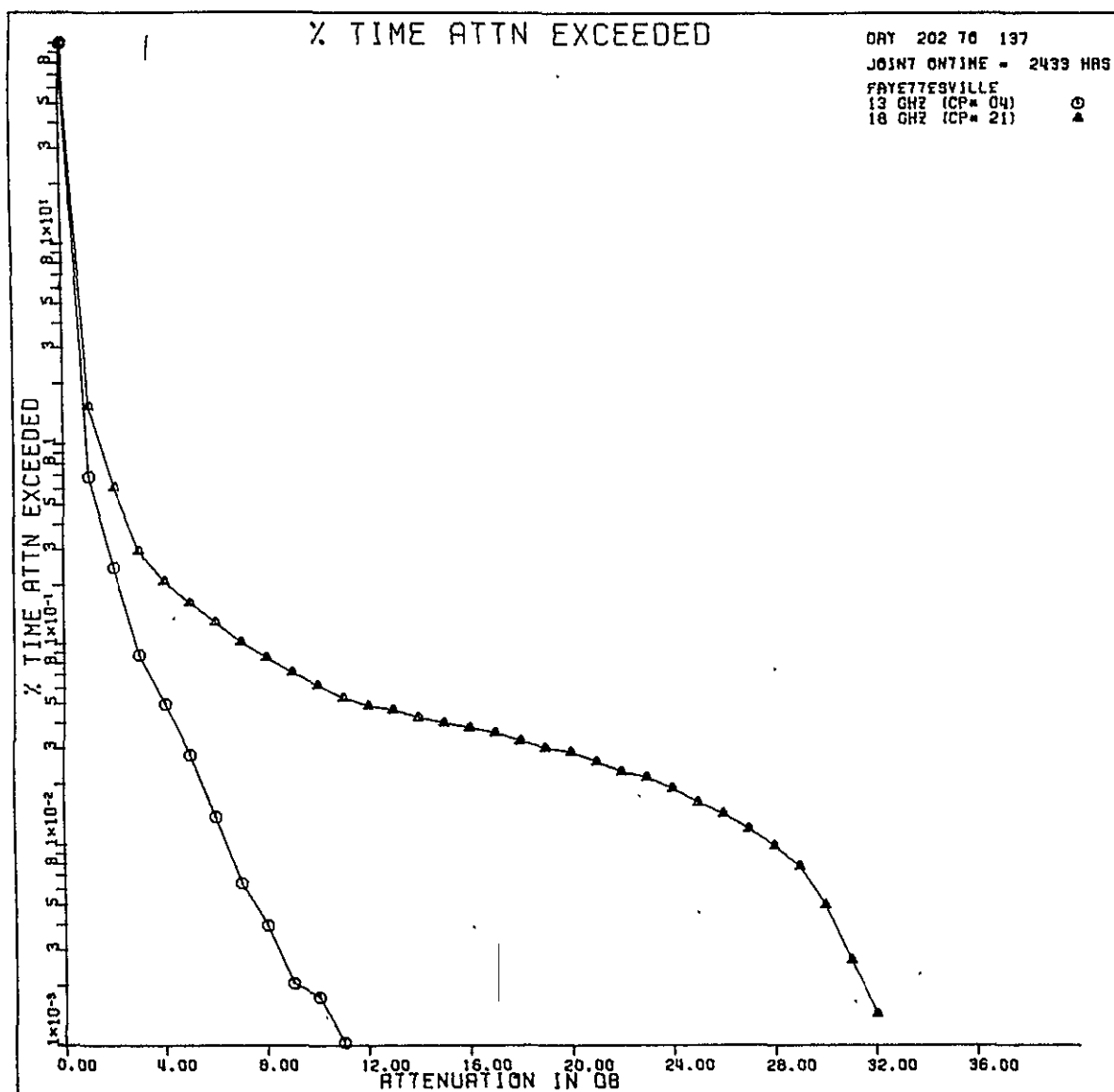


Figure 5-7. Fayetteville, 13 and 18 GHz, Percent-of-Time Attenuation Exceeded



carrier only, (shown in Figure 5-1) the on time is 3961 hours. Checking the data base in some detail, the bulk of the difference in times occurs in the summer and fall quarters; so it is clear that, as expected in the eastern U.S.A. there is a major variation of cumulative statistics seasonally. This is no surprise, but the illustration is very graphic.

The major differences in the curves for attenuation exceedance statistics given in Figures 5-1, 5-4, and 5-7 occur at the lower percent times; the two curves for 13 GHz track reasonably down to about 0.2 percent-of-the time, but diverge sharply below about 0.1 percent-of-the time. A study of the climate records shows that there is a strong tendency for there to be less heavy rain in this area in fall, winter, and early spring. Mean total monthly rainfall is significantly greater in July and August than for any other months. This point is further reinforced when it is seen that the cumulative statistics for the rain data collected for one year (plotted in Figure 5-8) shows that the plotted rain data collected coincident with the 18-GHz carrier (CP# 21) cuts-off sharply near 80 mm/hr, while that for the 13-GHz carrier (CP# 4) contains significant data to above 110 mm/hr. Rain data will be further discussed below.

The 13- and 18-GHz cumulative attenuation statistics are also presented in tabular form in Tables 5-31 and 5-32 for 13- and 18-GHz operation, respectively. The individual fade events were also analyzed to provide correlation between fade depths at 13 and 18 GHz. This data is presented in detail in Table 5-33. The left hand column of the table gives the fade depth in dB at 13 GHz; the FAYV columns give the mean fade depth in dB and standard derivation of the many 18-GHz data points that entered into the mean. The meaning of this data is, that for a 13-GHz attenuation level of  $L$  dB (where  $L$  is a whole number),

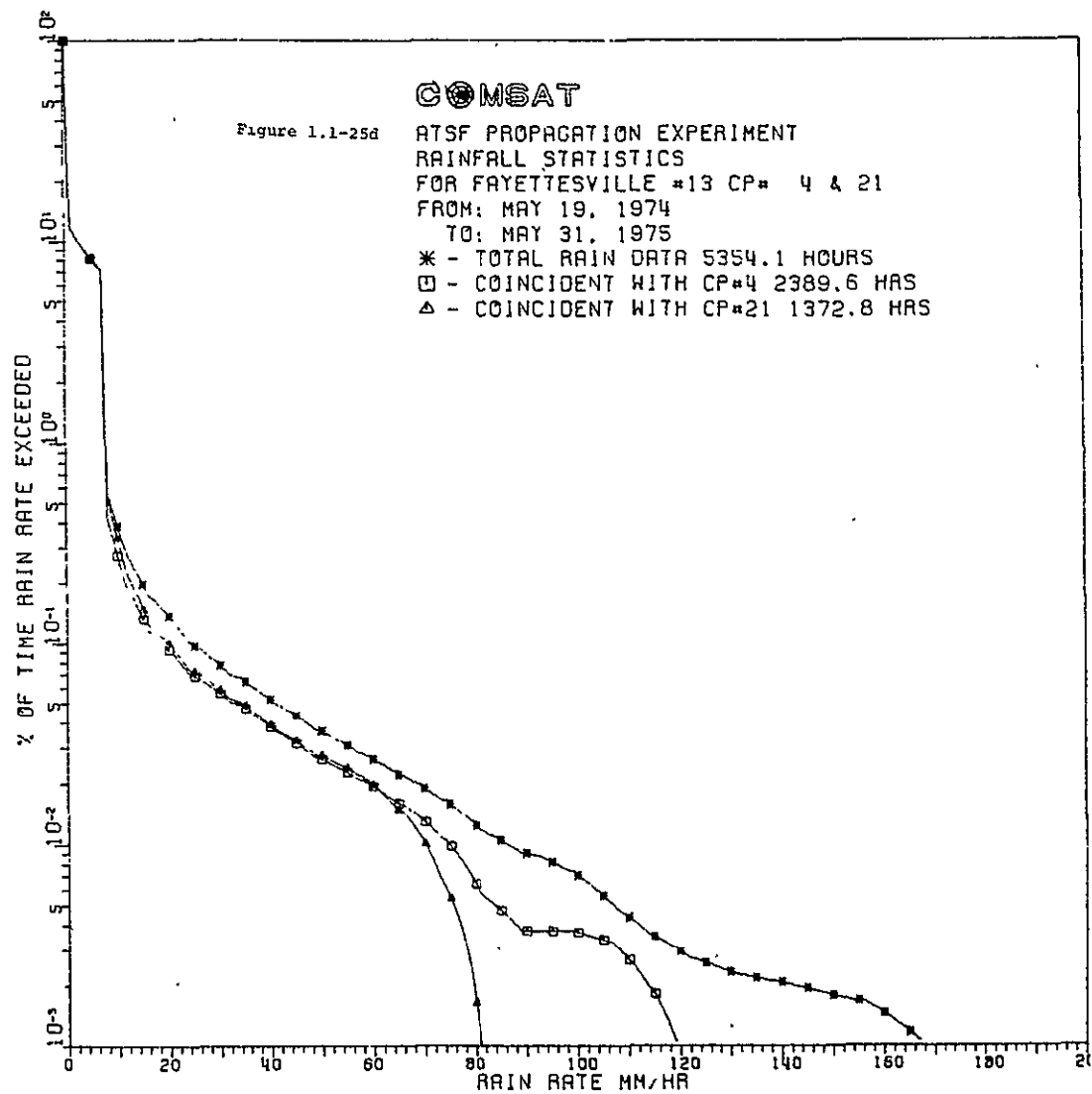


Figure 5-8. Rainfall Statistics for Fayetteville

Table 5-31. Percent-of-Time Attenuation Exceeded at  
Coincidentally Operating 13-GHz Sites

13 GHZ FREQ. BAND		% TIME ATTENUATION EXCEEDED AT COINCIDENTLY OPERATING SITES										0 202 TO 75 137			
DB	TMPA	ATL	NDR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W.IS	MIAM	MSU	OSU	B-C
1	0.52	4.70	1.70	0.69	1.30	0.65	4.84	0.01	6.79	0.25	0.70	0.27	3.36	0.25	0.60
2	0.27	1.34	0.71	0.24	0.36	0.22	2.68	0.0	5.96	0.16	0.41	0.05	2.04	0.07	0.27
3	0.15	0.14	0.32	0.09	0.15	0.05	0.17	0.0	3.50	0.11	0.22	0.01	1.35	0.02	0.14
4	0.12	0.09	0.23	0.05	0.09	0.02	0.01	0.0	1.92	0.09	0.14	0.01	1.04	0.00	0.09
5	0.10	0.06	0.20	0.03	0.05	0.01	0.00	0.0	1.07	0.07	0.10	0.01	0.81	0.00	0.06
6	0.08	0.03	0.18	0.01	0.03	0.01	0.00	0.0	0.60	0.05	0.06	0.01	0.58	0.00	0.04
7	0.05	0.03	0.16	0.01	0.02	0.01	0.00	0.0	0.39	0.04	0.03	0.01	0.34	0.00	0.02
8	0.04	0.02	0.15	0.00	0.01	0.00	0.00	0.0	0.25	0.03	0.02	0.00	0.17	0.00	0.02
9	0.03	0.01	0.14	0.00	0.01	0.00	0.00	0.0	0.17	0.02	0.01	0.00	0.09	0.00	0.01
10	0.03	0.01	0.13	0.00	0.00	0.00	0.00	0.0	0.12	0.02	0.01	0.00	0.04	0.00	0.01
11	0.02	0.00	0.12	0.00	0.00	0.00	0.00	0.0	0.10	0.01	0.01	0.00	0.02	0.00	0.00
12	0.02	0.00	0.09	0.00	0.00	0.00	0.00	0.0	0.09	0.01	0.00	0.00	0.01	0.00	0.00
13	0.01	0.00	0.03	0.00	0.00	0.0	0.00	0.0	0.08	0.01	0.00	0.00	0.00	0.00	0.00
14	0.01	0.00	0.02	0.00	0.00	0.0	0.00	0.0	0.06	0.01	0.00	0.00	0.00	0.00	0.00
15	0.01	0.00	0.01	0.00	0.00	0.0	0.00	0.0	0.04	0.00	0.00	0.00	0.00	0.00	0.00
16	0.01	0.00	0.01	0.00	0.00	0.0	0.0	0.0	0.03	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.01	0.00	0.0	0.0	0.0	0.0	0.02	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.01	0.00	0.0	0.0	0.0	0.0	0.02	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.01	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.00	0.00	0.00
21	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.00	0.00	0.00
22	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.00	0.00	0.00
23	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.00	0.00	0.00
24	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.00	0.00	0.00
25	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.00	0.00	0.00
26	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.00	0.00	0.00
27	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.0	0.00	0.00
28	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.0	0.00	0.00
29	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.0	0.00	0.00
30	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.0	0.00	0.00
31	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.0	0.0	0.00	0.00
32	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.00	0.00
33	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.00	0.00
34	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.00	0.00
35	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.00	0.00
36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
HOURS ON	978.	879.	663.	2433.	1616.	781.	1046.	37.	2672.	2002.	3557.	83.	2370.	1945.	2412.

Table 5-32. Percent-of-Time Attenuation Exceeded at Coincidentally Operating 18-GHz Sites

18 GHZ FREQ. BAND			% TIME ATTENUATION EXCEEDED AT COINCIDENTLY OPERATING SITES										0 202 TO 75 137				
DB	TMPA	ATL	N. OR	FAYV	ASHV	NSHV	WASH	PHIL	ANDV	DETR	W. IS	MIAM	MSU	OSU	B-C		
1	2.49	1.67	1.42	1.53	5.58	1.79	6.79	4.35	10.99	3.17	1.61	0.51	3.47	0.66	1.84		
2	1.35	0.70	0.52	0.61	4.65	0.54	5.83	3.51	8.94	2.24	0.73	0.28	2.81	0.23	0.95		
3	0.58	0.31	0.23	0.30	3.92	0.15	5.45	3.22	7.22	0.96	0.31	0.19	1.94	0.08	0.34		
4	0.38	0.23	0.17	0.21	3.50	0.09	5.31	3.21	6.16	0.25	0.19	0.16	1.03	0.05	0.21		
5	0.31	0.19	0.14	0.16	3.20	0.07	5.28	3.21	5.02	0.15	0.14	0.15	0.33	0.03	0.15		
6	0.27	0.16	0.12	0.13	2.80	0.06	5.26	3.21	3.90	0.12	0.11	0.14	0.19	0.02	0.11		
7	0.24	0.13	0.11	0.10	2.37	0.05	5.26	3.21	3.03	0.10	0.08	0.13	0.17	0.02	0.09		
8	0.22	0.11	0.10	0.09	1.73	0.05	5.25	3.21	2.09	0.09	0.06	0.13	0.15	0.02	0.07		
9	0.20	0.10	0.09	0.07	1.33	0.05	5.25	3.21	1.23	0.08	0.05	0.12	0.14	0.02	0.06		
10	0.18	0.08	0.09	0.06	0.95	0.04	5.25	3.21	0.56	0.07	0.05	0.12	0.12	0.02	0.05		
11	0.16	0.08	0.08	0.05	0.50	0.04	5.25	3.21	0.33	0.06	0.04	0.12	0.11	0.01	0.04		
12	0.15	0.07	0.07	0.05	0.13	0.04	5.25	3.21	0.21	0.06	0.04	0.12	0.10	0.01	0.03		
13	0.14	0.06	0.07	0.05	0.08	0.04	5.25	3.21	0.15	0.06	0.03	0.11	0.09	0.01	0.03		
14	0.13	0.06	0.06	0.04	0.06	0.03	5.25	3.21	0.12	0.05	0.03	0.10	0.09	0.01	0.03		
15	0.12	0.05	0.06	0.04	0.06	0.03	5.16	3.21	0.11	0.05	0.03	0.10	0.08	0.01	0.03		
16	0.11	0.05	0.05	0.04	0.05	0.03	4.95	3.21	0.09	0.04	0.03	0.10	0.08	0.01	0.02		
17	0.11	0.04	0.05	0.04	0.05	0.03	4.85	3.19	0.08	0.04	0.02	0.10	0.07	0.01	0.02		
18	0.10	0.03	0.04	0.03	0.05	0.03	4.77	3.08	0.07	0.03	0.02	0.10	0.07	0.01	0.02		
19	0.10	0.03	0.04	0.03	0.04	0.03	4.44	2.95	0.04	0.03	0.02	0.10	0.06	0.01	0.02		
20	0.09	0.03	0.03	0.03	0.04	0.02	3.78	2.86	0.02	0.03	0.02	0.09	0.06	0.01	0.02		
21	0.08	0.03	0.03	0.03	0.03	0.02	2.97	2.62	0.02	0.02	0.02	0.09	0.05	0.01	0.02		
22	0.09	0.02	0.03	0.02	0.03	0.02	2.20	1.90	0.01	0.02	0.01	0.09	0.05	0.01	0.01		
23	0.07	0.02	0.02	0.02	0.03	0.02	1.14	0.91	0.01	0.02	0.01	0.08	0.05	0.01	0.01		
24	0.06	0.02	0.02	0.02	0.02	0.02	0.45	0.34	0.01	0.02	0.01	0.08	0.04	0.01	0.01		
25	0.06	0.02	0.02	0.02	0.02	0.01	0.02	0.21	0.01	0.01	0.01	0.07	0.04	0.01	0.01		
26	0.05	0.02	0.01	0.01	0.02	0.01	0.00	0.18	0.01	0.01	0.01	0.07	0.04	0.01	0.01		
27	0.05	0.02	0.01	0.01	0.02	0.01	0.00	0.03	0.01	0.01	0.01	0.06	0.03	0.00	0.01		
28	0.04	0.02	0.01	0.01	0.02	0.01	0.00	0.03	0.01	0.01	0.01	0.05	0.03	0.00	0.01		
29	0.04	0.01	0.01	0.01	0.01	0.01	0.00	0.03	0.01	0.01	0.01	0.04	0.03	0.00	0.01		
30	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.03	0.00	0.01	0.01	0.04	0.02	0.00	0.01		
31	0.03	0.01	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.01	0.01	0.04	0.02	0.00	0.01		
32	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.01	0.01	0.03	0.01	0.00	0.01		
33	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.01	0.00	0.03	0.01	0.00	0.01		
34	0.02	0.01	0.0	0.00	0.00	0.0	0.00	0.02	0.00	0.00	0.00	0.02	0.01	0.00	0.00		
35	0.01	0.00	0.0	0.00	0.00	0.0	0.00	0.01	0.00	0.00	0.00	0.02	0.01	0.0	0.00		
36	0.01	0.00	0.0	0.0	0.00	0.0	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.0	0.00		
37	0.00	0.00	0.0	0.0	0.00	0.0	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.0	0.00		
38	0.00	0.00	0.0	0.0	0.00	0.0	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.0	0.00		
39	0.00	0.00	0.0	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.01	0.00	0.0	0.00		
40	0.00	0.00	0.0	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.00	0.00	0.0	0.00		
HOURS ON	978.	879.	663.	2423.	1616.	781.	1046.	37.	2672.	2002.	3557.	83.	2370.	1945.	2412.		

Table 5-33. Correlation of 13- and 18-GHz  
Attenuation by Site

CORRELATION OF 13 GHZ & 18 GHZ ATTENUATION BY SITES											
		TAPA		ATL		NCP		FAYV		ASHV	
13 GHZ DB	MEAN	S. DEV.	MEAN	S. DEV.	MEAN	S. DEV.	MEAN	S. DEV.	MEAN	S. DEV.	
1	2.377	2.695	2.175	3.307	1.950	1.835	1.951	1.648	5.780	3.344	
2	3.402	1.450	3.198	2.353	3.325	1.404	3.317	1.489	6.399	2.963	
3	6.085	2.282	4.876	1.527	5.075	1.007	5.123	1.194	6.500	2.469	
4	7.595	1.696	6.524	1.979	6.909	0.996	6.762	1.035	8.505	2.616	
5	8.456	1.448	8.312	2.217	8.618	1.189	8.030	1.253	10.072	2.529	
6	9.844	1.758	12.074	2.210	10.867	0.957	9.239	1.156	11.848	2.409	
7	11.186	2.295	14.222	1.950	12.154	1.561	10.167	1.067	15.175	4.341	
8	13.091	2.087	16.417	1.470	15.000	1.673	13.056	1.268	17.174	4.350	
9	16.818	3.601	15.923	2.615	16.857	1.125	15.000	0.0	18.522	3.752	
10	18.722	0.731	18.700	1.000	17.889	2.131	16.250	1.479	22.429	2.195	
11	20.706	1.177	20.000	0.0	20.667	0.943	0.0	0.0	24.333	0.472	
12	22.769	0.891	22.000	0.0	20.000	1.000	0.0	0.0	17.000	0.0	
13	24.222	0.629	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
14	26.500	1.258	0.0	0.0	14.000	0.0	0.0	0.0	14.000	0.0	
15	28.125	1.166	0.0	0.0	17.000	0.0	0.0	0.0	0.0	0.0	
16	29.230	0.542	0.0	0.0	0.0	0.0	0.0	0.0	22.000	0.0	
17	29.667	0.472	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
20	0.0	0.0	0.0	0.0	0.0	0.0	23.000	0.0	0.0	0.0	
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
22	29.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
25	0.0	0.0	0.0	0.0	25.000	0.0	0.0	0.0	0.0	0.0	
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

all data points at 18 GHz were included that occurred simultaneously with fades at 13 GHz between L and (L+1) dB. Then the mean and standard deviation of the 18-GHz values were taken. Thus, in the FAYV columns of Table 5-30, the mean 18-GHz fade level corresponding to a 13-GHz fade of 6 dB is 9.2 dB, with a standard deviation of 1.16 dB. The plot of 18-GHz mean fade level as a function of 13-GHz fade level is given in Figure 5-9. It is a quite respectable line with a slope of about 1.6 dB (18 GHz)/dB (13 GHz).

#### 5.2.7 QUARTERLY AND MONTHLY STATISTICS

There are tables of statistical data for each month and plots and tables for statistical data for each quarter corresponding to each plot and table discussed above for the duration of the experiments for the 13- and 18-GHz carriers from the Fayetteville site to the ATS-6 satellite. There are about 28 plots and 128 tables provided in the quarterly studies of each dual-frequency site and many more tables containing the monthly data. These may be found in the Data Analysis Report: Part II<sup>[6]</sup>, which provides a complete set of computer analysis output.

#### 5.3 DIVERSITY SITE ANALYSIS

Each of the three diversity sites (Boston, Mass.; Columbus, Ohio; and Starkville, Miss.) consisted of a more or less east-west line of four sites, spaced at intervals of approximately 8, 12 and 4 miles, so that separations of about 4, 8, 12, 16, 20, and 24 miles were available. Each diversity

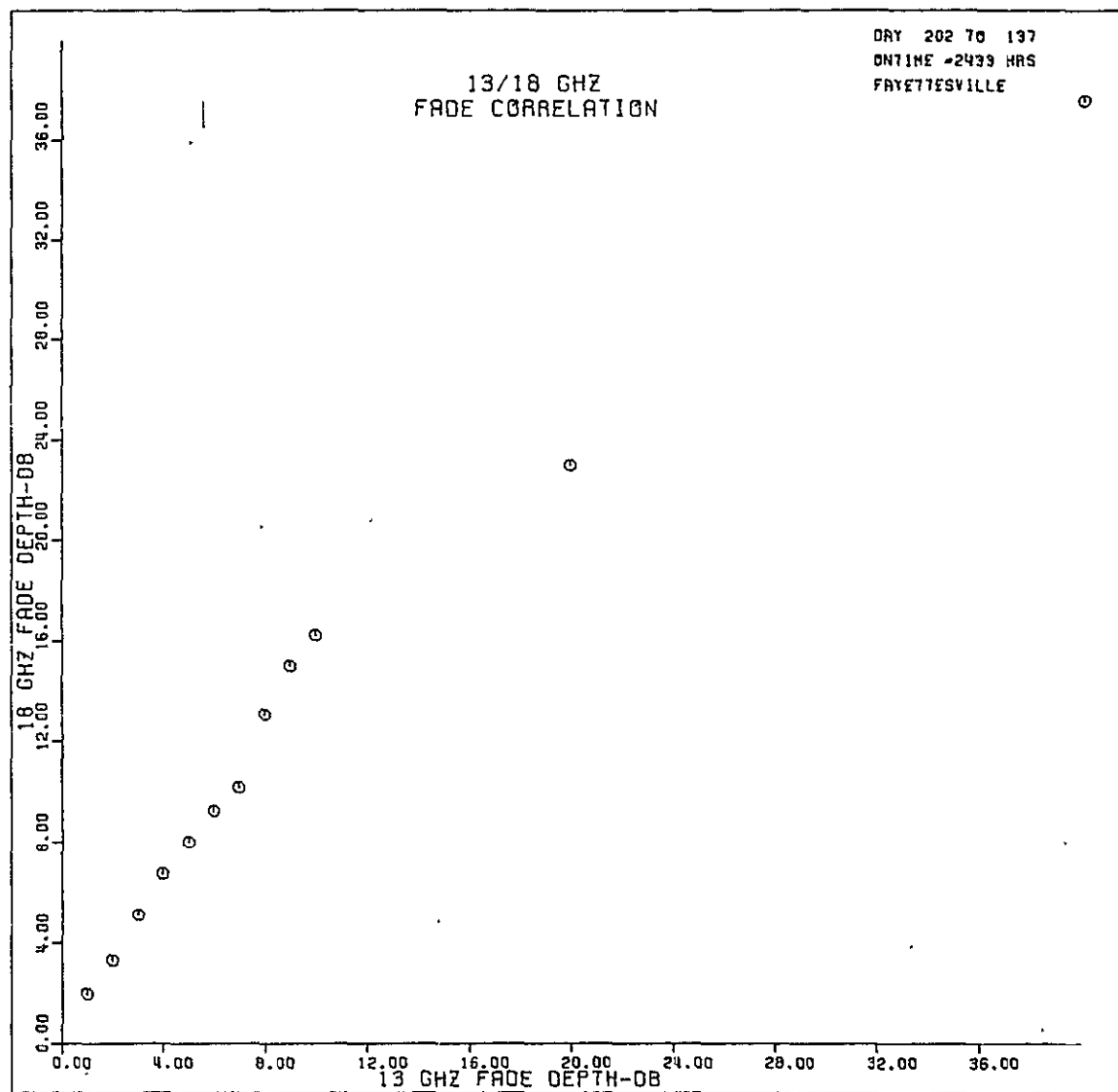


Figure 5-9. 13/18-GHz Fade Correlation at Fayetteville

site had one dual-frequency GTT which transmitted both 13- and 18-GHz carriers and three single-frequency GTTs which transmitted 18-GHz carriers only. Also, point rain data was collected at each GTT. The attenuation data collected by the DAQS and the rain data were analyzed to produce cumulative statistics for each of the carrier slant paths individually, for each pair of the 18-GHz slant paths jointly, and for simple diversity (the better of either at any one instant) for each 18-GHz path pair. Finally, diversity improvement was calculated.

The Boston locale data will be used as an example. A map of the Boston diversity site is given in Figure 5-10. Table 5-34 lists the Boston GTT CP designations and on times, pairings, pair-separations, and joint on times.

#### 5.3.1 CUMULATIVE ATTENUATION STATISTICS FOR EACH PATH

Percent-of-time exceeded is plotted against rain-induced attenuation fade depth for each carrier transmitted in Figure 5-11. The curves have the same shape as those discussed earlier. The curve for the 13-GHz carrier (CP# 15) exceedance lies well below the curve for the 18-GHz carrier (CP# 38) transmitted along the same path. Note that while the shape of the 18-GHz curves are all quite similar, in the exceedance ranges of greatest interest (0.01% to 0.5%), there was clearly a best and a worst site, for the limited amount of time the experiment was conducted. The data for the individual sites is presented in tabular form in Table 5-35.



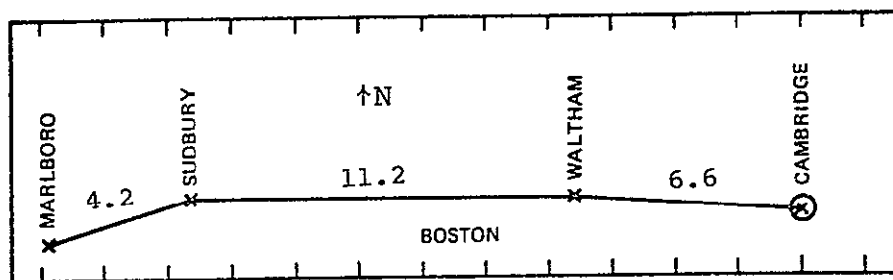


Figure 5-10. Boston Diversity Site Configuration

Table 5-34. Diversity Site Analysis - All Data Processed  
Total Hrs. Per Site for Boston

COMSAT ATS-F PROPAGATION EXPERIMENT DIVERSITY SITE ANALYSIS - ALL DATA PROCESSED FOR BOSTON RECORDED FROM: 0:22:20 ON JULY 21, 1974 TO: 24: 0: 0 ON MAY 17, 1975		
CP #	FREQUENCY (GHZ)	TOTAL GOOD DATA (HOURS)
38	18	2729.5
39	18	3836.4
40	18	3851.6
37	18	3038.6
15	13	4104.7
SEPARATION (MILES)	PAIR (C°)	TOTAL GOOD DATA (HOURS)
4.2	39/37	2916.6
6.6	38/40	2659.2
11.2	39/40	3722.1
15.2	40/37	2927.7
17.8	38/39	2618.8
21.8	38/37	2253.2

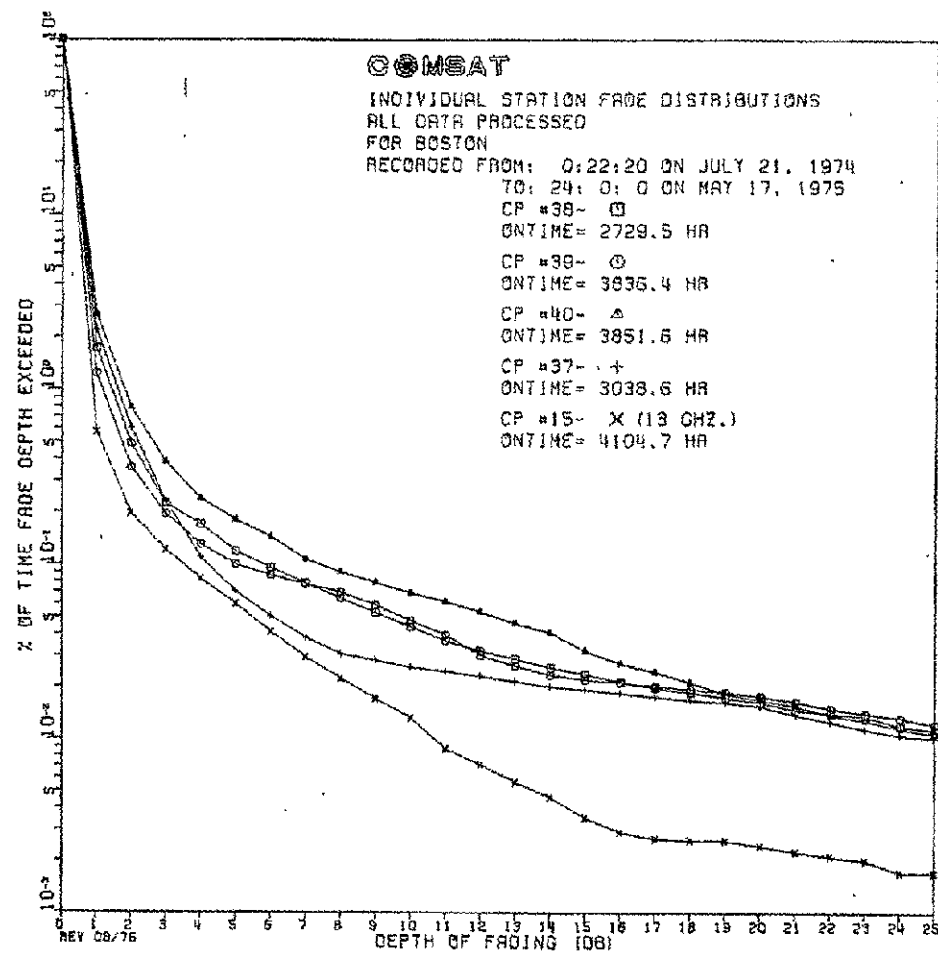


Figure 5-11. Individual Station Fade Distributions for Boston Diversity Sites

Table 5-35. Individual Fading Distributions for Boston

ATS-F DIVERSITY ANALYSIS FOR BOSTON  
 ALL DATA PROCESSED  
 RECORDED FROM: 0:22:20 CN JULY 21, 1974  
 TO: 24: 0: 0 CN MAY 17, 1975  
 INDIVIDUAL FADING DISTRIBUTIONS

	CP# 38 18 GHZ	CP# 39 19 GHZ	CP# 40 18 GHZ	CP# 37 18 GHZ	CP# 15 13 GHZ
0	100.00	100.00	100.00	100.00	100.00
1	1.7055	1.2338	2.6403	2.1613	0.5644
2	0.4863	0.3574	0.7825	0.5993	0.1950
3	0.2221	0.1944	0.3811	0.2275	0.1211
D 4	0.1690	0.1294	0.2352	0.1095	.08247
E 5	0.1185	0.1002	0.1791	.06985	.05908
P 6	.09553	.08641	0.1426	.05052	.04087
T 7	.07822	.07728	0.1064	.03793	.02936
H 8	.06366	.06927	.09009	.03077	.02211
9	.05285	.05871	.07841	.02822	.01699
O 10	.04396	.04757	.06848	.02575	.01316
F 11	.03654	.03955	.06121	.02444	.00877
12	.03197	.03017	.05329	.02287	.00713
F 13	.02885	.02633	.04595	.02139	.00566
A 14	.02574	.02333	.04076	.01990	.00463
D 15	.02363	.02190	.03200	.01917	.00353
I 16	.02125	.02111	.02707	.01827	.00292
N 17	.01960	.02020	.02428	.01744	.00268
G 18	.01850	.01922	.02110	.01670	.00262
19	.01731	.01864	.01824	.01621	.00262
D 20	.01630	.01759	.01675	.01547	.00244
B 21	.01475	.01642	.01545	.01382	.00225
22	.01401	.01499	.01370	.01259	.00213
23	.01346	.01401	.01279	.01144	.00201
24	.01191	.01329	.01155	.01053	.00171
25	.01127	.01212	.01071	.01012	.00171

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### 5.3.2 CUMULATIVE ATTENUATION STATISTICS FOR DIVERSITY PAIRS

Figure 5-12 through 5-17 show the joint cumulative attenuation statistics for the six pairs of sites. Each figure shows the exceedance curves (for two sites) for the data collected only when both sites were providing collectable data. Thus Figure 5-15 shows the exceedance curves for the carrier paths processed by CPs #40 and #37 (whose GTT sites were separated by 15.2 miles) for 2927.7 hours of simultaneous processible data or on time (as compared to 3851.6 and 3038.6 hours processible data recorded from CPs #40 and #37 shown in Figure 5-11). From these curves, it would seem to indicate that over the 10 months of the experiment, the path from the GTT site corresponding to CP #37 offered somewhat lower exceedance levels for the same percent-of-the time than the path for the carrier of CP #40, except at the very highest levels of attenuation. But the improvement offered by simple diversity over either individual path was even greater. However, even with diversity, margin requirements remain substantial. To quantify the discussion, the results for 0.02 percent-of-the time and 0.1 percent-of-the time are examined.

At 0.02 percent-of-the time, the exceedance level for the path of the carrier processed by CP #40 is about 15 dB, that corresponding to CP #37 is about 13 dB; but that for the diversity pair, i.e. for the better of either, is reduced to about 7.5 dB. For 0.1 percent-of-the time, the results are about 5.5 dB, 4.2 dB, and 2.8 dB respectively. Thus, it can be seen that the greatest dB improvement is at the higher attenuations, as would be expected from the generally cellular nature of the heavy rain causing the higher attenuations. However, there is still a substantial improvement at 0.1 percent-of-the time.

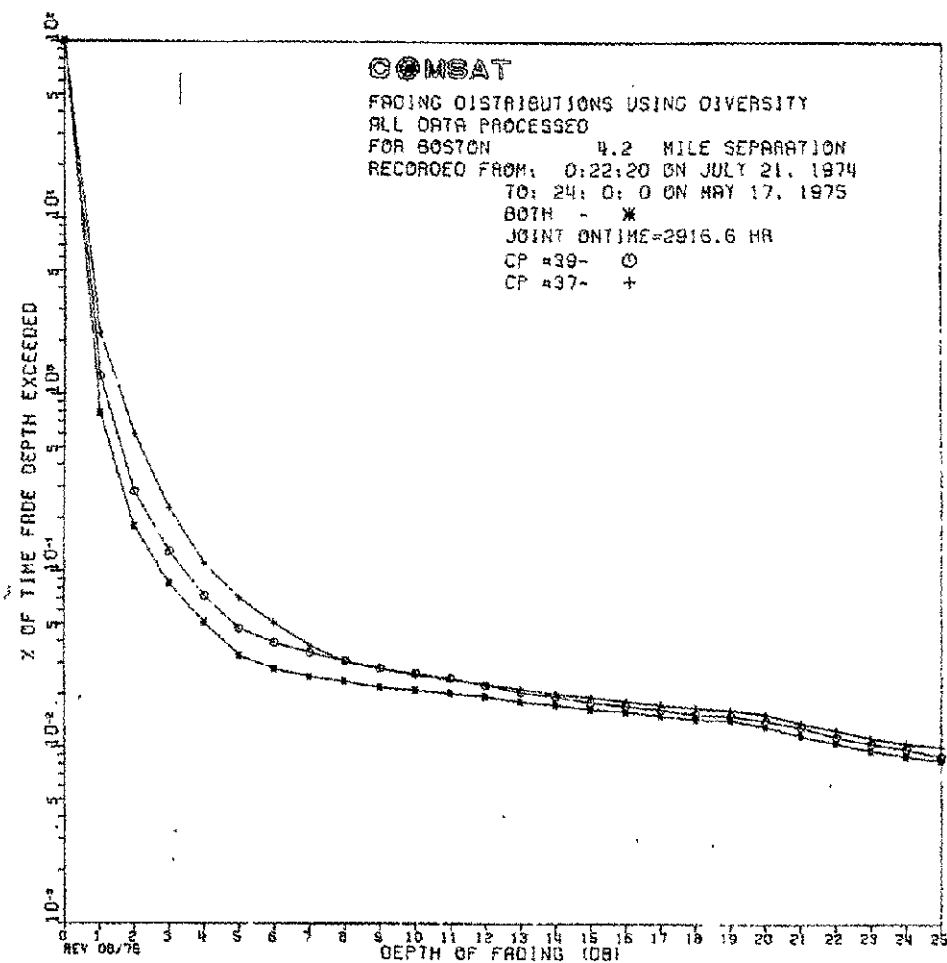


Figure 5-12. Fading Distributions Using Diversity at  
18 GHz for Boston, 4.2-Mile Separation

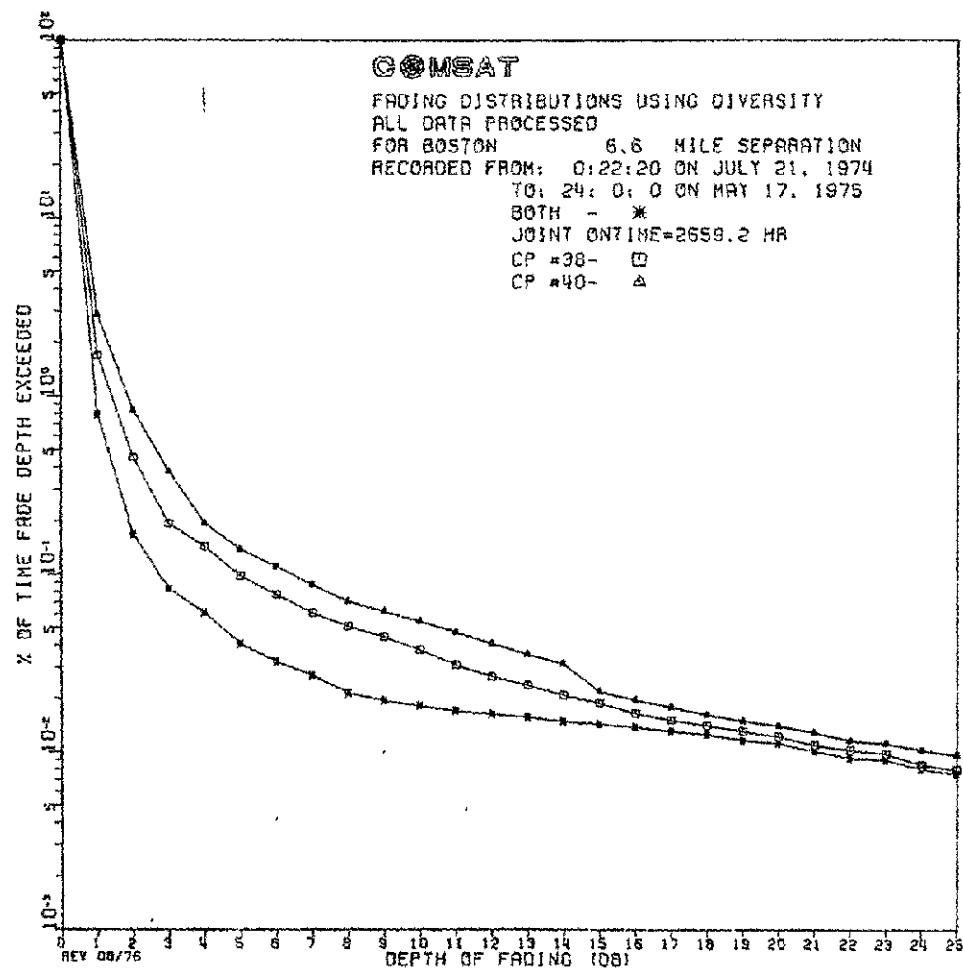


Figure 5-13. Fading Distributions Using Diversity at  
 18 GHz for Boston, 6.6-Mile Separation

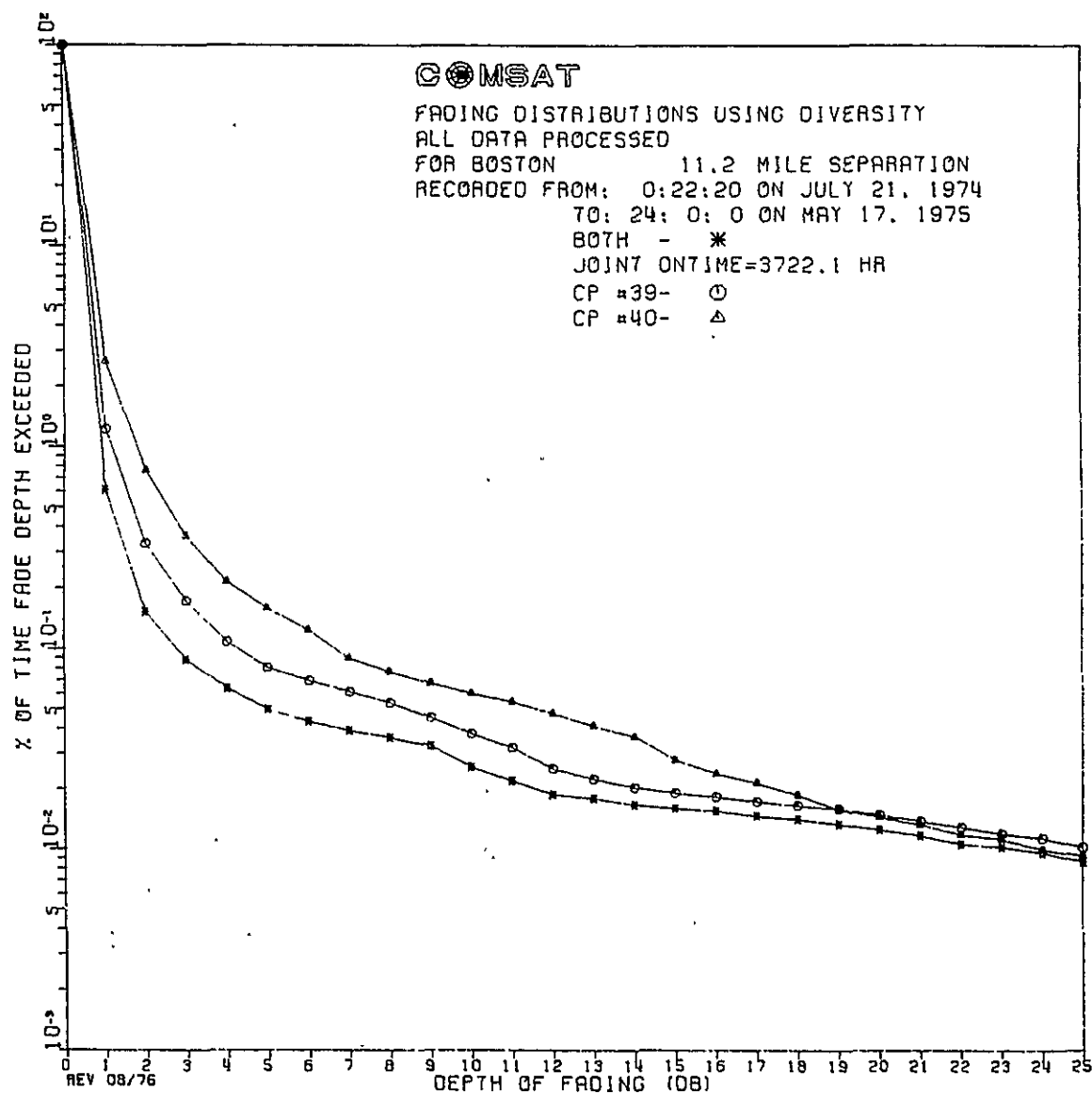


Figure 5-14. Fading Distributions Using Diversity at  
 18 GHz for Boston, 11.2-Mile Separation



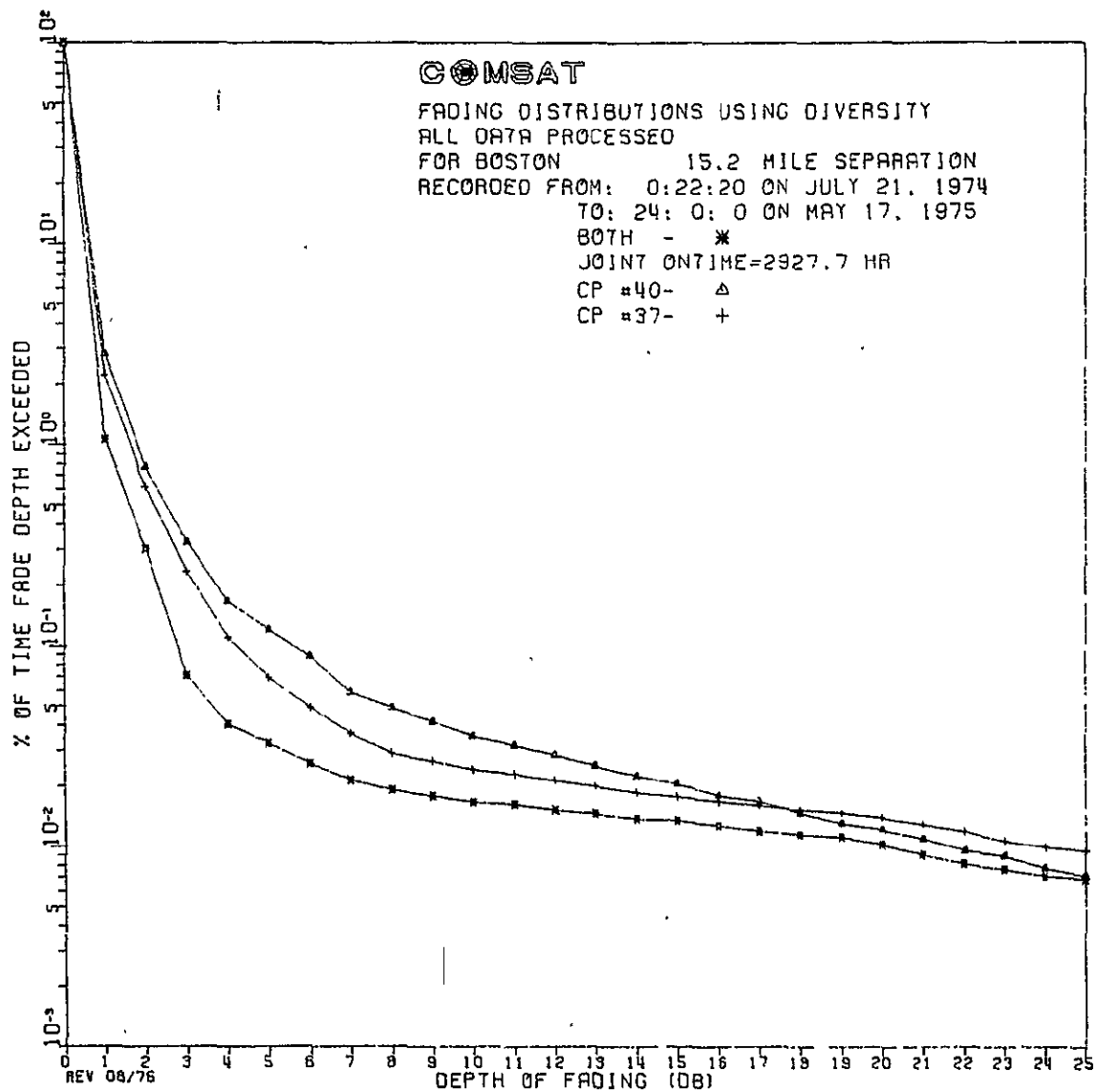


Figure 5-15. Fading Distributions Using Diversity  
 at 18 GHz for Boston, 15.2-Mile Separation

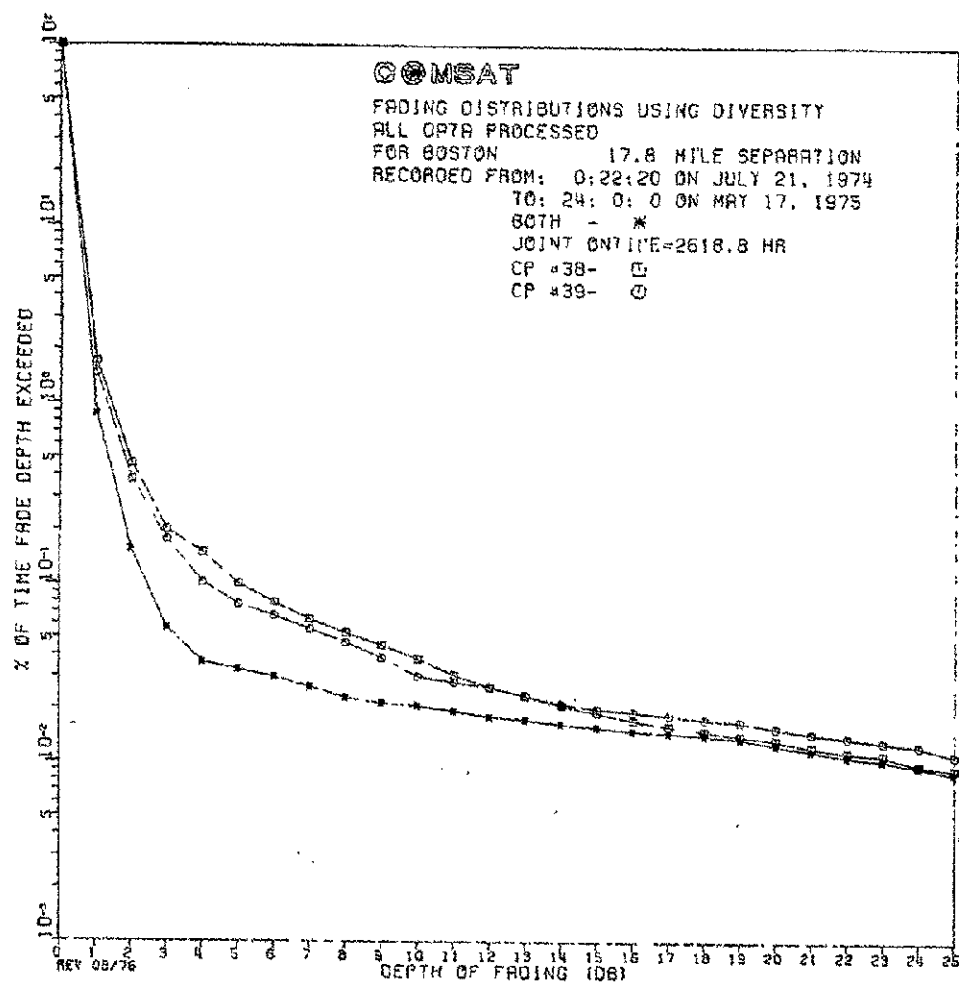


Figure 5-16. Fading Distributions Using Diversity at  
 18 GHz for Boston, 17.8-Mile Separation

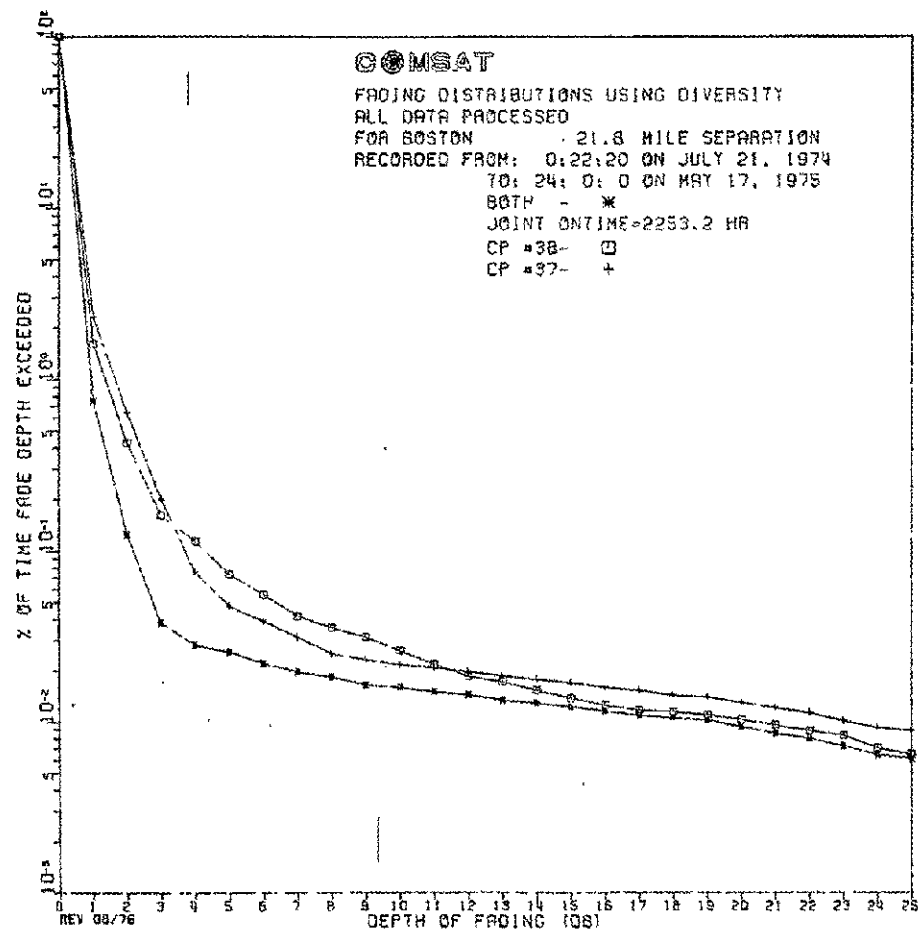


Figure 5-17. Fading Distributions Using Diversity at 18 GHz for Boston, 21.8-Mile Separation

One way of viewing the effects of diversity, is that it pulls the bend of the characteristic exceedance curve downward in percent-of-the time and toward lesser fade depth. If the curves are viewed as being asymptotic to two straight lines, which corresponds to the Rice and Holmberg [7] view of the rain rate statistics that caused the attenuation, then the effect of using diversity is to make the left asymptote steeper, i.e., the rate of change of percent-of-the time is increased for the first few dB of attenuation so that the diversity path suffers less attenuation for the same percent-of-the time exceeded.

Table 5-36 gives the attenuation data for the cumulative attenuation curves for the six diversity pairs. Figure 5-18 shows the plots of these data. From these plots it can be observed that for higher attenuations, the least advantage is offered by separations of 4.2, 11.7, and 17.8 miles, and the greatest advantage is offered by the greatest separation which was 21.8 miles. (Since there was no pattern of preference emerging from all three diversity locales, not too much should be read into this.)

### 5.3.3 IMPROVEMENT USING DIVERSITY

The diversity improvement data is shown in Figure 5-19 and given in Table 5-37. Diversity improvement is defined as the improvement in cumulative attenuation statistics offered by the use of the better of the pair of sites as compared to using the better of the two sites. (It is assumed that if only one site could be chosen, the one with the better cumulative attenuation statistics would be chosen.)

Table 5-36. Simple Switched Diversity Operation for Boston

ATS-F DIVERSITY ANALYSIS FOR BOSTON  
 ALL DATA PROCESSED  
 RECORDED FROM: 0:22:20 ON JULY 21, 1974  
 TO: 24: 0: 0 ON MAY 17, 1975  
 18 GHZ. FADING DISTRIBUTIONS USING  
 SIMPLE SWITCHED DIVERSITY OPERATION

	4.2 MILES	5.6 MILES	11.2 MILES	15.2 MILES	17.8 MILES	21.8 MILES
01	100.00	100.00	100.00	100.00	100.00	100.00
11	0.7787	0.7870	0.6078	1.0600	0.8677	0.7464
21	0.1797	0.1582	0.1523	0.3020	0.1552	0.1243
31	.08554	.08301	.08709	.07087	.05670	.03795
D 41	.05126	.06083	.06334	.04056	.03628	.02818
E 51	.03334	.04071	.04984	.03253	.03313	.02574
P 61	.02794	.03234	.04332	.02579	.02997	.02197
T 71	.02546	.02708	.03902	.02135	.02644	.01964
H 81	.02383	.02153	.03620	.01904	.02310	.01831
91	.02194	.01955	.03271	.01776	.02148	.01653
O 101	.02126	.01824	.02572	.01648	.02081	.01598
F 111	.02040	.01711	.02190	.01614	.01947	.01509
121	.01963	.01645	.01874	.01511	.01804	.01442
F 131	.01834	.01579	.01793	.01443	.01747	.01343
A 141	.01757	.01485	.01659	.01366	.01651	.01287
D 151	.01663	.01438	.01592	.01341	.01585	.01220
I 161	.01611	.01391	.01545	.01264	.01518	.01154
N 171	.01534	.01316	.01464	.01187	.01480	.01087
G 181	.01466	.01269	.01410	.01144	.01432	.01054
191	.01449	.01175	.01337	.01110	.01384	.01021
D 201	.01337	.01128	.01249	.01016	.01270	.00932
B 211	.01183	.01015	.01169	.00905	.01184	.00854
221	.01080	.00931	.01061	.00820	.01098	.00799
231	.00977	.00912	.01021	.00769	.01050	.00721
241	.00909	.00808	.00960	.00709	.00964	.00644
251	.00857	.00761	.00866	.00683	.00888	.00610

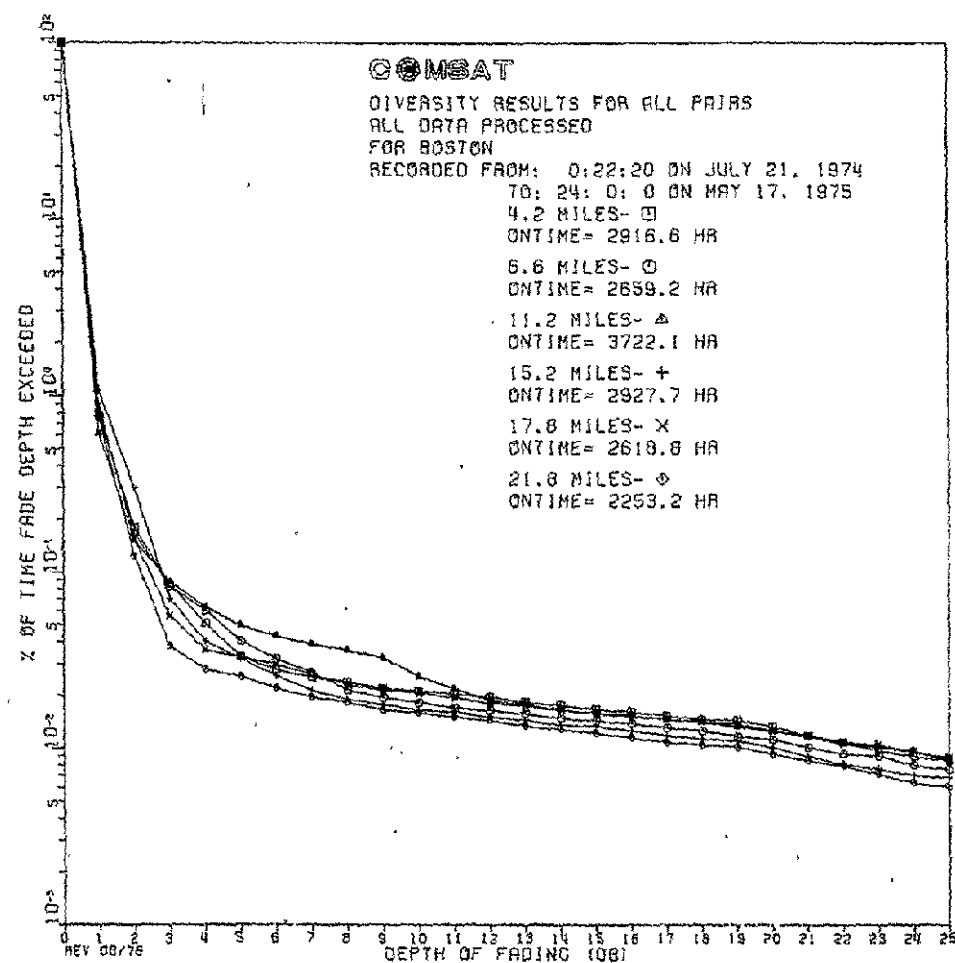


Figure 5-18. Diversity Results at 18 GHz for all Pairs for Boston

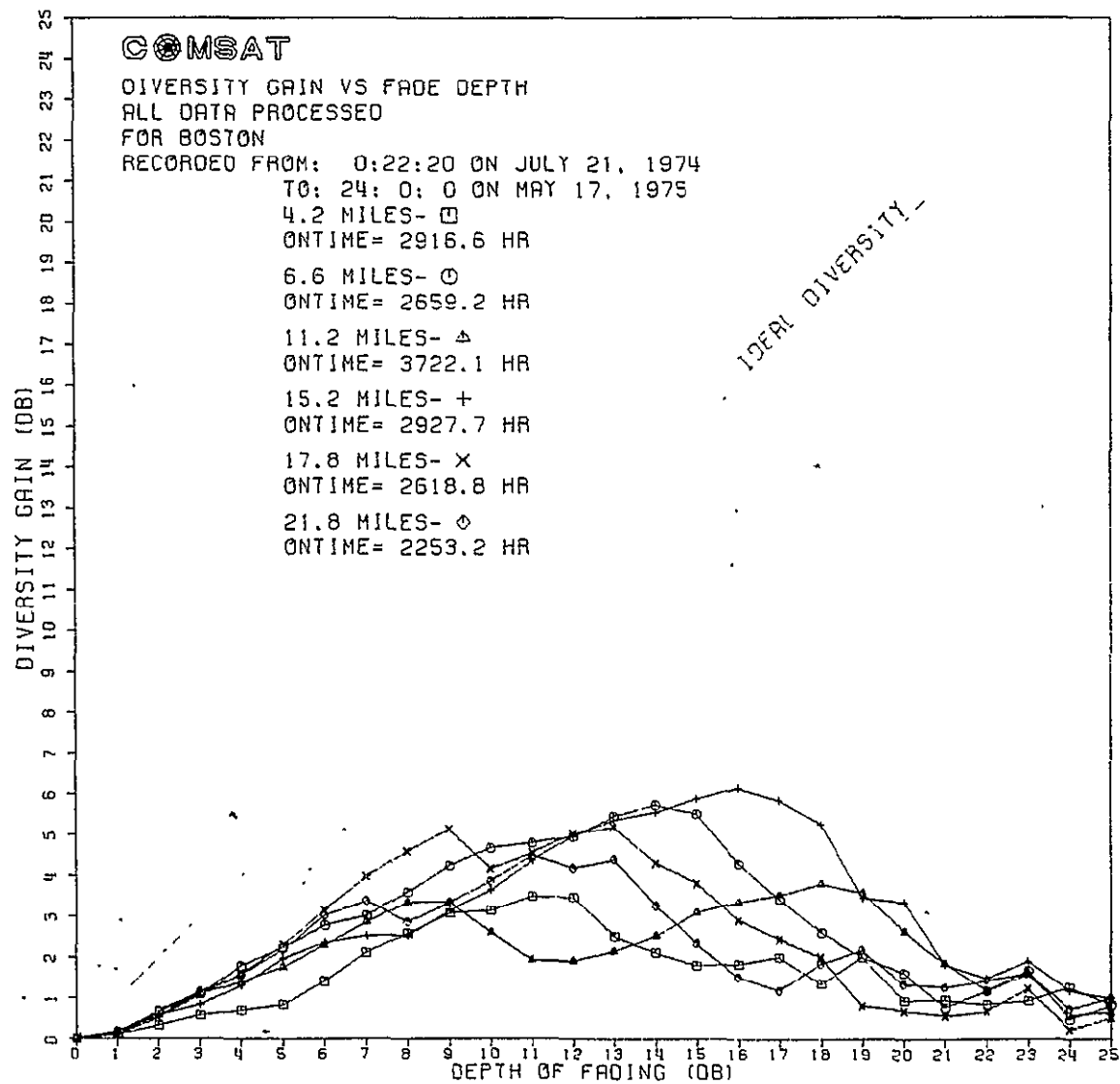


Figure 5-19. Diversity Gain vs Fade Depth at 18 GHz for Boston

Table 5-37. Diversity Gain vs Depth of Fading for Boston

## ATS-F DIVERSITY ANALYSIS FOR BOSTON

ALL DATA PROCESSED

RECORDED FROM: 0:22:20 ON JULY 21, 1974

TO: 24: 0: 0 ON MAY 17, 1975

## DIVERSITY GAIN VS. DEPTH OF FADING

	4.2 MILES	6.6 MILES	11.2 MILES	15.2 MILES	17.8 MILES	21.8 MILES
1	0.1	0.2	0.1	0.2	0.1	0.2
2	0.3	0.6	0.6	0.6	0.5	0.7
3	0.6	1.1	1.1	0.8	1.1	1.1
4	0.7	1.8	1.4	1.3	1.6	1.6
D 5	0.8	2.2	1.7	2.0	2.3	2.2
E 6	1.4	2.8	2.3	2.4	3.2	3.0
P 7	2.1	3.0	2.9	2.5	4.0	3.4
T 8	2.6	3.6	3.3	2.5	4.6	2.9
H 9	3.1	4.2	3.3	3.1	5.1	3.3
10	3.1	4.7	2.6	3.6	4.2	3.9
O 11	3.5	4.8	1.9	4.4	4.6	4.5
F 12	3.5	5.0	1.9	5.0	5.0	4.2
13	2.5	5.5	2.1	5.3	5.2	4.4
F 14	2.1	5.7	2.5	5.5	4.3	3.3
A 15	1.8	5.5	3.1	5.9	3.8	2.3
D 16	1.8	4.3	3.3	6.1	2.9	1.5
I 17	2.0	3.4	3.5	5.8	2.4	1.2
N 18	1.3	2.6	3.8	5.3	2.0	1.8
G 19	2.0	2.0	3.6	3.5	0.8	2.2
20	0.9	1.6	2.6	3.3	0.7	1.3
D 21	0.9	3.8	1.9	1.8	0.6	1.3
B 22	0.8	1.2	1.2	1.5	0.7	1.4
23	0.9	1.7	1.6	1.9	1.2	1.6
24	1.3	0.5	0.6	1.2	0.2	0.7
25	0.8	0.8	0.7	1.0	0.5	1.0



The diversity improvement increases steadily up to about 9 dB; thereafter the data becomes irregular. It would seem that this might be explained in terms of the relatively small sample, where a few events dominate, and for those, a particular station in the pair was favored, due to the storm tracks of those rain events. Some indication of this should be seen in the rain data.

#### 5.4 RAINFALL INTENSITY DATA

Rain data was collected at 23 sites. At 11 of the sites, the processible rain data was collected for the bulk of the experiment; at 6 more sites, processible rain data was collected for more than half the time. Of the 39 carriers, only 10 carriers (excluding the Andover carriers for which rain was not collected) fall into the category for which processible rain data was sparse. Over 110,000 hours of processible rain data was collected, or roughly 6000 hours per site, on average, at the 19 sites where appreciable rain and attenuation data was collected. This information is detailed, for each site, in Table 5-38.

The rain data was collected using tipping-bucket type rain gauges which tipped every time 0.01 in. of rainfall was collected. The number of tips were recorded. Due to evaporation these gauges are not accurate at the very lowest rain rates; or at the very highest rain rates, because of the limitations imposed by the mechanism. However, for the range of greatest interest (5 mm/hr to 150 mm/hr) the accuracy is acceptable. The method used to analyze the data resulted in a tendency for the curve to form steps at the lowest and highest levels, also.

Table 5-38. Total Rainfall

ATSF PROPAGATION EXPERIMENT  
 TOTAL RAINFALL  
 FROM: MAY 19, 1974  
 TO: MAY 31, 1975

-----SITE-----	RAIN (MM)	-----HOURS OF DATA-----			
		TOTAL DATA	COINCIDENT CP# HOURS	COINCIDENT CP# HOURS	
BOSTON #2	508.1	7115.0	15 3319.3	38 2088.7	
COLUMBUS #3	651.8	7999.0	14 3096.6	35 2371.1	
STARKVILLE #4	843.2	6366.2	13 2847.8	33 2657.3	
MIAMI #5	63.0	4413.5	12 1493.9	30 70.4	
ITHACA #6	98.5	1943.5	29 827.0		
DETROIT #7	117.1	1948.2	10 487.9	27 441.9	
ANDOVER #8	0.0	0.0	9 0.0	26 0.0	
PHILADELPHIA #9	12.4	453.7	8 92.2	25 0.0	
WASHINGTON #10	391.8	3651.7	7 1851.7	24 786.9	
NASHVILLE #11	619.0	4562.9	6 988.5	23 1583.7	
ASHEVILLE #12	0.0	48.0	5 37.6	22 33.1	
FAYETTESVILLE #13	761.0	5354.1	4 2389.6	21 1372.8	
NEW ORLEANS #14	813.3	6026.7	3 1396.5	20 951.9	
ATLANTA #15	289.7	641.5	2 0.0	19 0.0	
TAMPA #16	352.4	6058.0	1 2598.6	18 1206.2	
BOSTON #17	0.0	0.0	40 0.0		
BOSTON #18	750.3	7835.7	39 3488.1		
BOSTON #19	405.0	6219.5	37 2784.1		
WALLOPS ISLAND #20	326.8	5145.9	11 2846.1	36 2380.6	
COLUMBUS #21	594.9	6667.3	34 2383.4		
COLUMBUS #22	508.8	7199.6	32 2385.1		
COLUMBUS #23	88.4	4289.5	31 2101.6		
STARKVILLE #24	423.3	2048.6	28 492.1		
STARKVILLE #25	482.2	3270.0	17 941.2		
STARKVILLE #26	636.3	3988.5	16 1210.0		

The number of tips in time intervals of 1 minute and 52.5 seconds were counted and entered into the computer, where the data was processed to produce exceedance plots of rain rate exceeded for a given percent-of-the time. The Fayetteville exceedance plot is given in Figure 5-20 and the same data is tabulated in Table 5-39. Note that rain rate exceedance data is provided for the total period of rain data collection and for rain data collected coincident with processible data for each carrier. It clearly shows that rain did not fall at a rate greater than about 80 mm/hr when 18-GHz data was being collected, whereas the cut-off for the 13-GHz data was more like 110 mm/hr, and the maximum rainfall rates measured exceeded 160 mm/hr (a very respectable rate indeed). The rain rate exceedance curves are quite noticeably asymptotic to two straight lines, with the bend in the curve occurring between 10 and 20 mm/hr. This is consistent with the Rice and Holmberg model for rainfall rates in the U.S.A.<sup>(6)</sup>, which postulates that there are two modes of rainfall that make up the total annual rainfall: lighter, more widespread rainfall and heavy rainfall that falls from intense rain cells. Two constants: the ratio of the total rain from heavy rainfall to the total annual rainfall,  $\beta$ , and the total annual rainfall,  $M$ , are sufficient to approximate, quite closely, smooth curves of a shape similar to the total rain rate exceedance curve. Similar rain rate exceedance data is shown for the Boston diversity sites in Figures 5-21 through 5-23 and Tables 5-40 through 5-42. (Note that there was no rain data collected at the GTT site for Boston CP #40.)

It is clear from the Boston and Fayetteville rain data that there was much less heavy rain in the Boston, Mass. area between May 1974 and May 1975 than at Fayetteville, N.C. The rain rate at Fayetteville for 0.01 percent-of-the time was

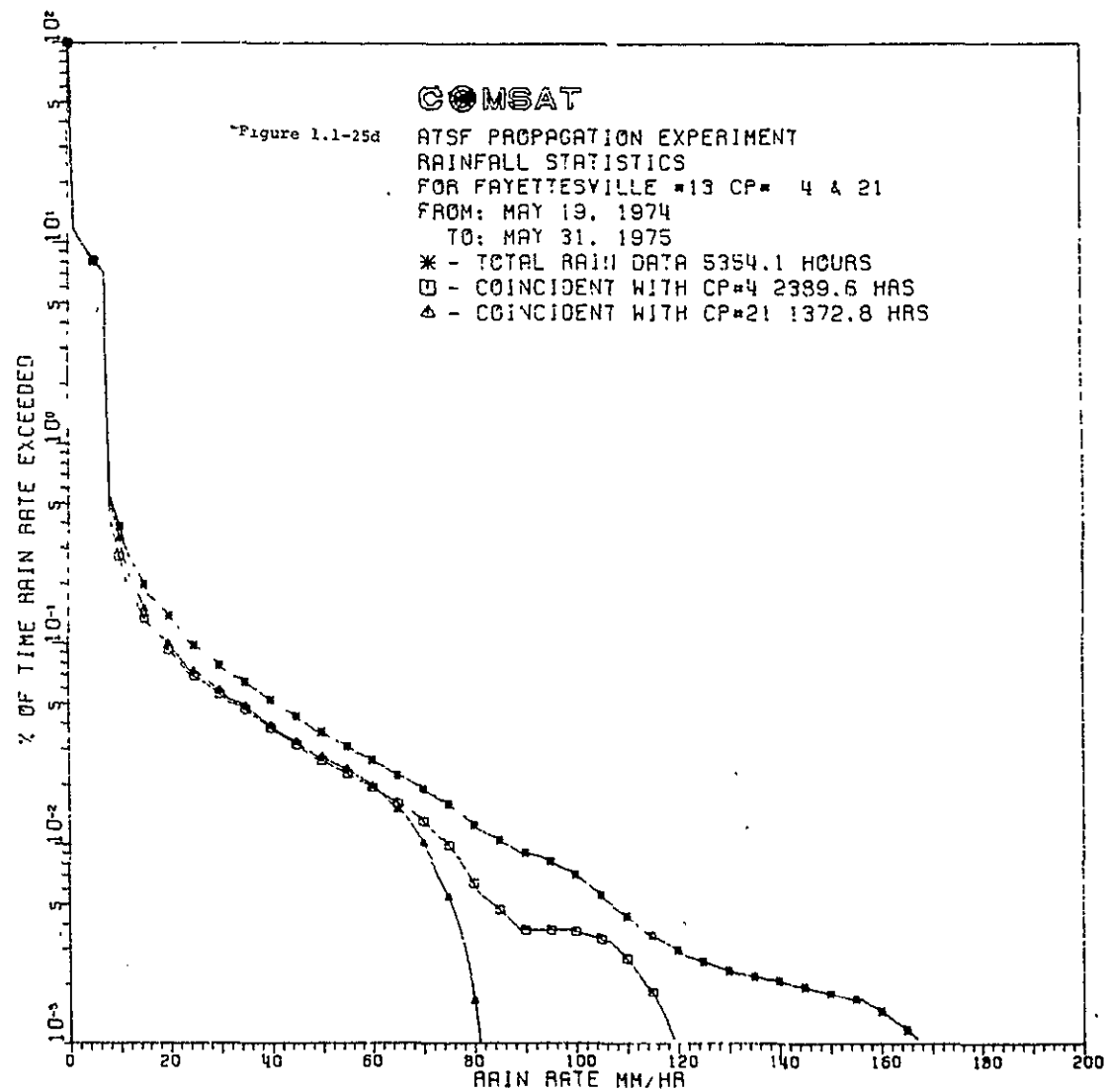


Figure 5-20. Rainfall Statistics for Fayetteville #13

Table 5-39. Rainfall Statistics for Fayetteville #13

ATSF PROPAGATION EXPERIMENT  
 RAINFALL STATISTICS FOR FAYETTESVILLE #13  
 FROM: MAY 19, 1974  
 TO: MAY 31, 1975

	TOTAL RAIN DATA TIME	COINCIDENT WITH CP# 4	COINCIDENT WITH CP#21
0	100.00	100.00	100.00
2	10.713	10.549	10.708
4	8.9647	8.8153	8.9495
6	7.7150	7.5763	7.6933
8	.56259	.42327	.53413
10	.38620	.27464	.33654
12	.27418	.18762	.22142
14	.22272	.15061	.17160
16	.17348	.11561	.12430
18	.15705	.10533	.11306
20	.13810	.09350	.09985
25	.09846	.06920	.07277
30	.07839	.05654	.05901
35	.06495	.04764	.04917
40	.05264	.03854	.03934
45	.04395	.03201	.03278
R 50	.03662	.02668	.02775
A 55	.03123	.02291	.02393
I 60	.02679	.01959	.01989
N 65	.02243	.01613	.01497
70	.01918	.01312	.01016
R 75	.01595	.00992	.00546
A 80	.01260	.00647	.00164
T 85	.01058	.00477	.00044
E 90	.00911	.00377	.00000
95	.00827	.00377	.00000
M 100	.00711	.00370	.00000
M 105	.00563	.00339	.00000
110	.00440	.00270	.00000
P 115	.00353	.00182	.00000
E 120	.00297	.00088	.00000
R 125	.00261	.00031	.00000
130	.00233	.00000	.00000
H 135	.00219	.00000	.00000
R 140	.00207	.00000	.00000
145	.00193	.00000	.00000
150	.00179	.00000	.00000
155	.00168	.00000	.00000
160	.00146	.00000	.00000
165	.00118	.00000	.00000
170	.00090	.00000	.00000
175	.00084	.00000	.00000
180	.00084	.00000	.00000
185	.00056	.00000	.00000
190	.00028	.00000	.00000
195	.00000	.00000	.00000
200	.00000	.00000	.00000

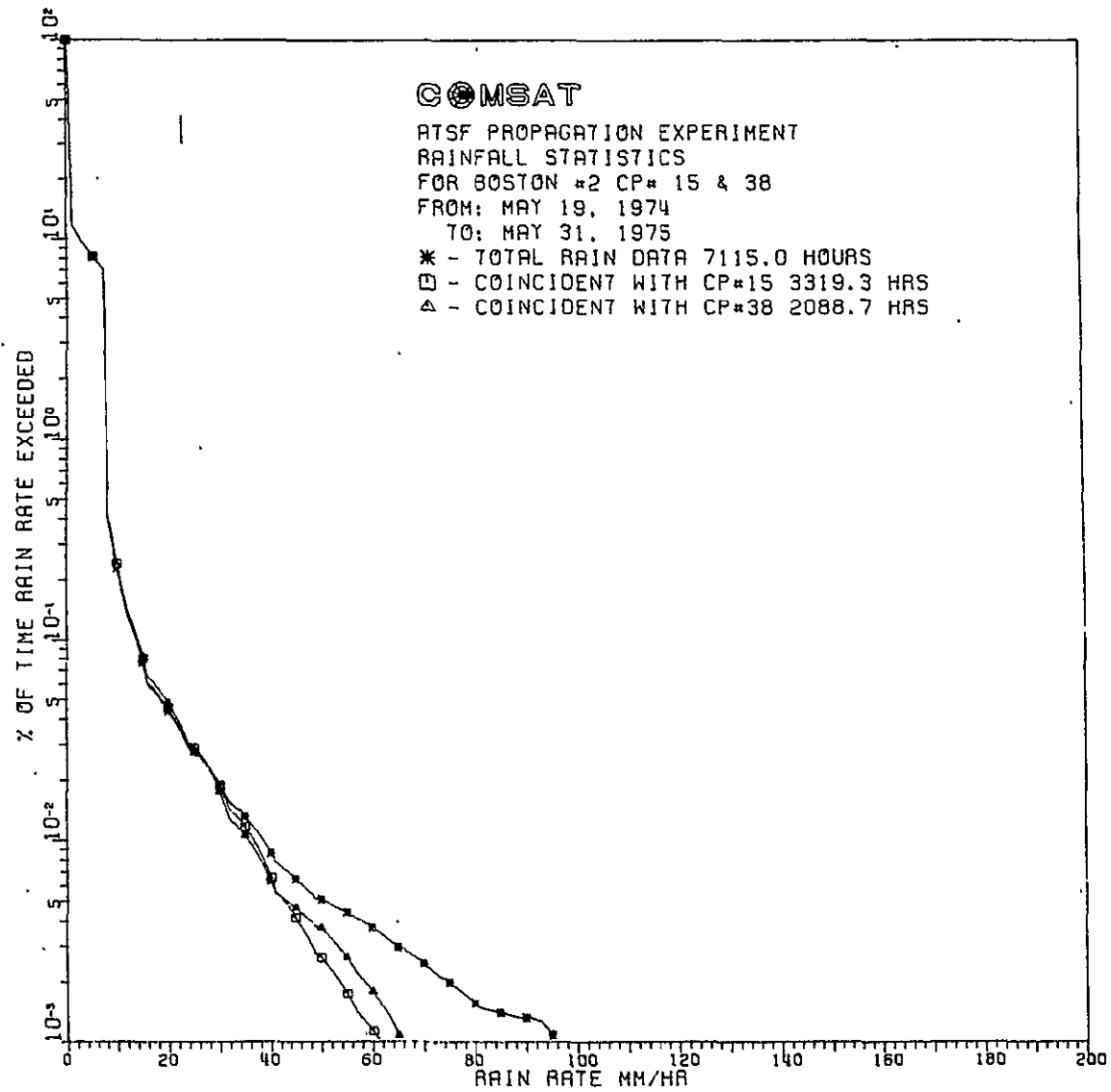


Figure 5-21. Rainfall Statistics for Boston #2

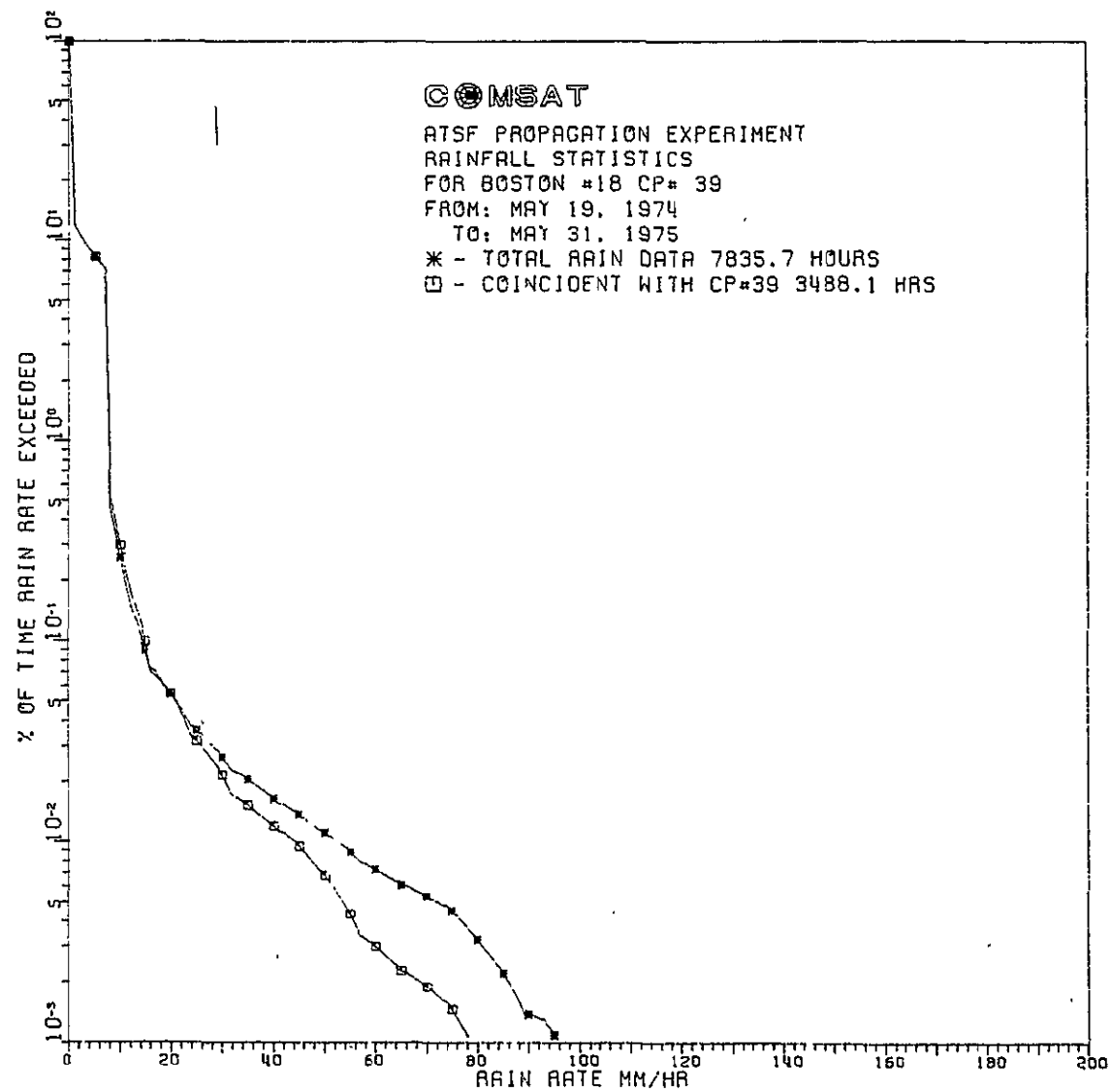


Figure 5-22. Rainfall Statistics for Boston #18

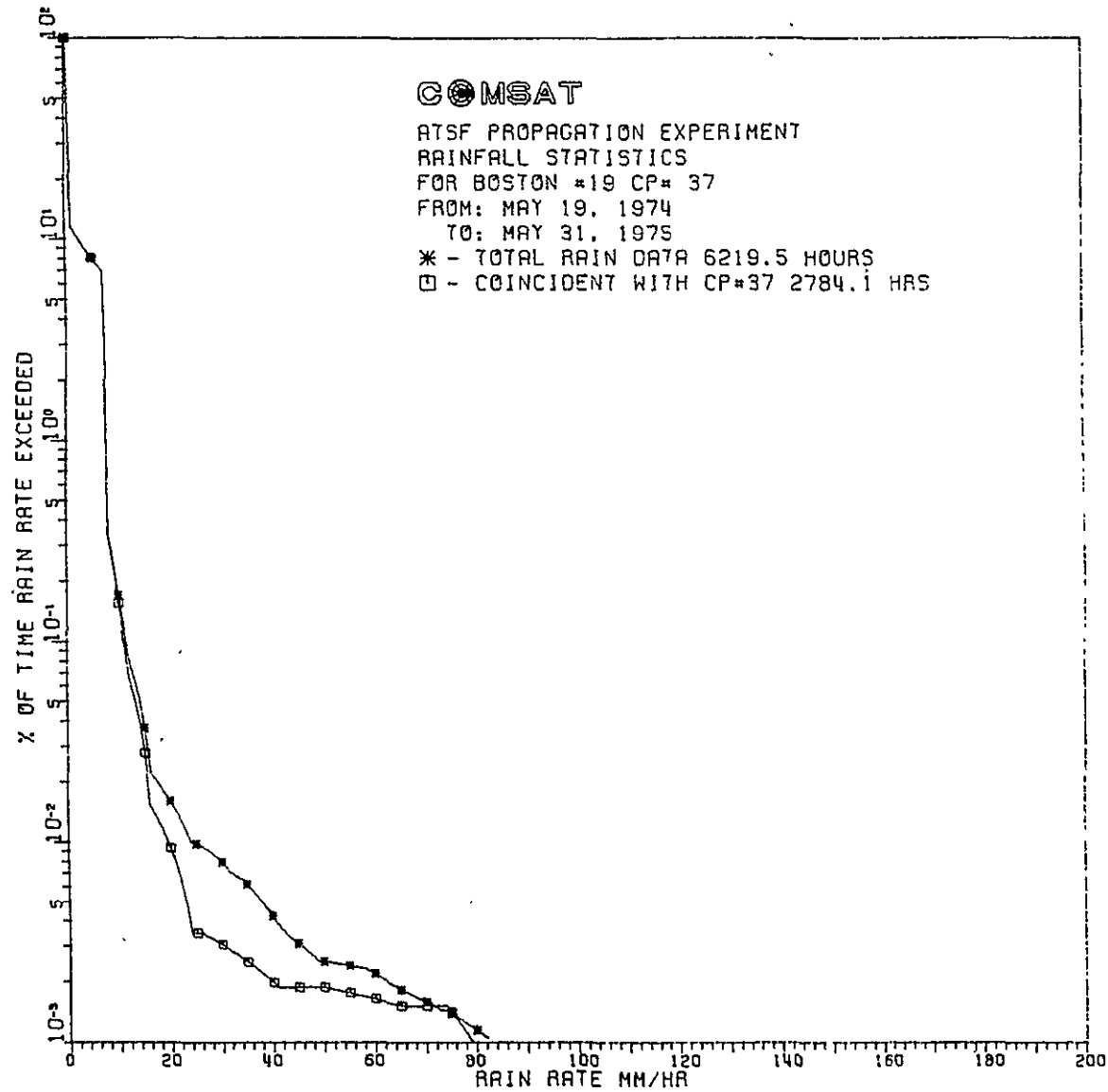


Figure 5-23. Rainfall Statistics for Boston #19



Table 5-40. Rainfall Statistics for Boston #2

ATSF PROPAGATION EXPERIMENT  
 RAINFALL STATISTICS FOR BOSTON #2  
 FROM: MAY 19, 1974  
 TO: MAY 31, 1975

	TOTAL RAIN DATA TIME	COINCIDENT WITH CP#15	COINCIDENT WITH CP#38
01	100.00	100.00	100.00
21	10.567	10.606	10.611
41	8.8193	8.8525	8.8573
61	7.5705	7.5989	7.6043
81	.40947	.43578	.44199
101	.22968	.24123	.23848
121	.13049	.14052	.13702
141	.09484	.10064	.10119
161	.05980	.06113	.06557
181	.05244	.05369	.05788
201	.04437	.04563	.04855
251	.02766	.02893	.02880
301	.01915	.01878	.01767
351	.01332	.01182	.01063
401	.00873	.00660	.00632
451	.00652	.00420	.00467
R 501	.00514	.00267	.00373
A 551	.00443	.00176	.00266
I 601	.00374	.00113	.00180
N 651	.00298	.00068	.00108
701	.00248	.00050	.00079
R 751	.00199	.00027	.00043
A 801	.00157	.00005	.00007
T 851	.00140	.00000	.00000
E 901	.00132	.00000	.00000
951	.00108	.00000	.00000
M 1001	.00064	.00000	.00000
M 1051	.00020	.00000	.00000
1101	.00000	.00000	.00000
P 1151	.00000	.00000	.00000
E 1201	.00000	.00000	.00000
R 1251	.00000	.00000	.00000
1301	.00000	.00000	.00000
H 1351	.00000	.00000	.00000
R 1401	.00000	.00000	.00000
1451	.00000	.00000	.00000
1501	.00000	.00000	.00000
1551	.00000	.00000	.00000
1601	.00000	.00000	.00000
1651	.00000	.00000	.00000
1701	.00000	.00000	.00000
1751	.00000	.00000	.00000
1801	.00000	.00000	.00000
1851	.00000	.00000	.00000
1901	.00000	.00000	.00000
1951	.00000	.00000	.00000
2001	.00000	.00000	.00000

Table 5-41. Rainfall Statistics for Boston #18

ATSF PROPAGATION EXPERIMENT		
RAINFALL STATISTICS FOR BOSTON #18		
FROM: MAY 19, 1974		
TO: MAY 31, 1975		
	TOTAL RAIN DATA TIME	COINCIDENT WITH CP#39
0	100.00	100.00
2	10.646	10.748
4	8.8870	8.9736
6	7.6307	7.7060
8	.46747	.53889
10	.25783	.29870
12	.14823	.17453
14	.10930	.12428
16	.07115	.07472
18	.06361	.06562
20	.05471	.05493
25	.03597	.03194
30	.02665	.02154
35	.02058	.01529
40	.01643	.01201
45	.01369	.00948
R 50	.01116	.00679
A 55	.00884	.00436
I 60	.00728	.00300
N 65	.00610	.00228
70	.00538	.00189
R 75	.00455	.00146
A 80	.00326	.00082
T 85	.00221	.00034
E 90	.00138	.00000
95	.00109	.00000
M 100	.00064	.00000
M 105	.00024	.00000
110	.00000	.00000
P 115	.00000	.00000
E 120	.00000	.00000
R 125	.00000	.00000
130	.00000	.00000
H 135	.00000	.00000
R 140	.00000	.00000
145	.00000	.00000
150	.00000	.00000
155	.00000	.00000
160	.00000	.00000
165	.00000	.00000
170	.00000	.00000
175	.00000	.00000
180	.00000	.00000
185	.00000	.00000
190	.00000	.00000
195	.00000	.00000
200	.00000	.00000

Table 5-42. Rainfall Statistics for Boston #19

ATSF PROPAGATION EXPERIMENT  
 RAINFALL STATISTICS FOR BOSTON #19  
 FROM: MAY 19, 1974  
 TO: MAY 31, 1975

	TOTAL RAIN DATA TIME	COINCIDENT WITH CP#37
0	100.00	100.00
2	10.506	10.489
4	8.7603	8.7451
6	7.5133	7.4994
8	.34983	.33620
10	.17042	.15565
12	.08125	.06598
14	.05152	.04039
16	.02238	.01528
18	.01927	.01234
20	.01604	.00939
25	.00984	.00350
30	.00798	.00307
35	.00620	.00253
40	.00427	.00199
45	.00311	.00189
R 50	.00253	.00189
A 55	.00241	.00177
I 60	.00219	.00165
N 65	.00183	.00153
70	.00159	.00153
R 75	.00140	.00142
A 80	.00116	.00092
T 85	.00092	.00041
E 90	.00072	.00000
95	.00072	.00000
M 100	.00068	.00000
M 105	.00043	.00000
110	.00019	.00000
P 115	.00000	.00000
E 120	.00000	.00000
R 125	.00000	.00000
130	.00000	.00000
H 135	.00000	.00000
R 140	.00000	.00000
145	.00000	.00000
150	.00000	.00000
155	.00000	.00000
160	.00000	.00000
165	.00000	.00000
170	.00000	.00000
175	.00000	.00000
180	.00000	.00000
185	.00000	.00000
190	.00000	.00000
195	.00000	.00000
200	.00000	.00000

38 mm/hr (at the dual-frequency GTT which transmitted the carriers processed by CPs #15 and #38), 52 mm/hr (CP #39), and 25 mm/hr (CP #37). The total rainfall collected at these three GTT sites were 508, 750, and 405 mm, respectively. Even the Boston GTT site where total rain collected is highest does not approach the rain intensity at Fayetteville. This is quite reasonable because Fayetteville is located inside the severe thunderstorm region whereas Boston is located far outside the region.

The variation among the three Boston GTT sites is also quite great and the possibility of a strong microclimate effect exists. However, more and longer term data would have to be obtained and analyzed to provide a firm basis for conclusions.

## 5.5 EXTRAPOLATED FADE STATISTICS

Because more hours of processible rain data than processible attenuation data was collected at many of the GTT sites, it has been thought useful to extrapolate the results to cover the period when either processible rain or processible attenuation data was collected.

It is well known that point rain data at a GTT site and slant-path attenuation data from that site do not bear an event relationship, especially for the higher attenuations and heavier rains, because it is perfectly possible for there to be a heavy rain cell on a segment of the path not including the GTT site where, perhaps, only light rain fell, and conversely, for there to be heavy rain falling at the GTT from a rain cell largely lying off the slant path. On the other hand, experience has shown that there appears to be a reasonably good relationship between the long-term cumulative statistics for the point

rain at the transmit site and the slant-path attenuation. It is assumed that this relationship holds for the hours of joint point rain and path attenuation.

The collected data for each carrier at each site was sorted into three sets:

- a. Rain and attenuation data collected at times when processible attenuation and processible rain data were both collected for a particular carrier,
- b. Processible rain data collected at times when processible attenuation data was not collected, and
- c. Processible attenuation data collected at times when processible rain data was not collected for that carrier.

It was assumed that for the data collected in set a., the cumulative statistics of point rain and rain-induced attenuation fade depth were statistically related through the percent-of-the time coordinate; for example, the point rain rate at 0.03 percent-of-the time corresponded to the rain-induced slant-path fade depth at 0.03 percent-of-the time; and further, this fact could be used to extrapolate from the statistics of the data of set a. to find the cumulative attenuation statistics for the period of time corresponding to the time for which processible rain data was collected but not processible attenuation data of set b. and also to find the cumulative rain rate statistics for the period of time corresponding to the time for which processible attenuation data was collected, but not processible rain data of set c.

This was done, and the results are shown in Figures 5-24 through 5-29 and given in Tables 5-43 through 5-47. The overall

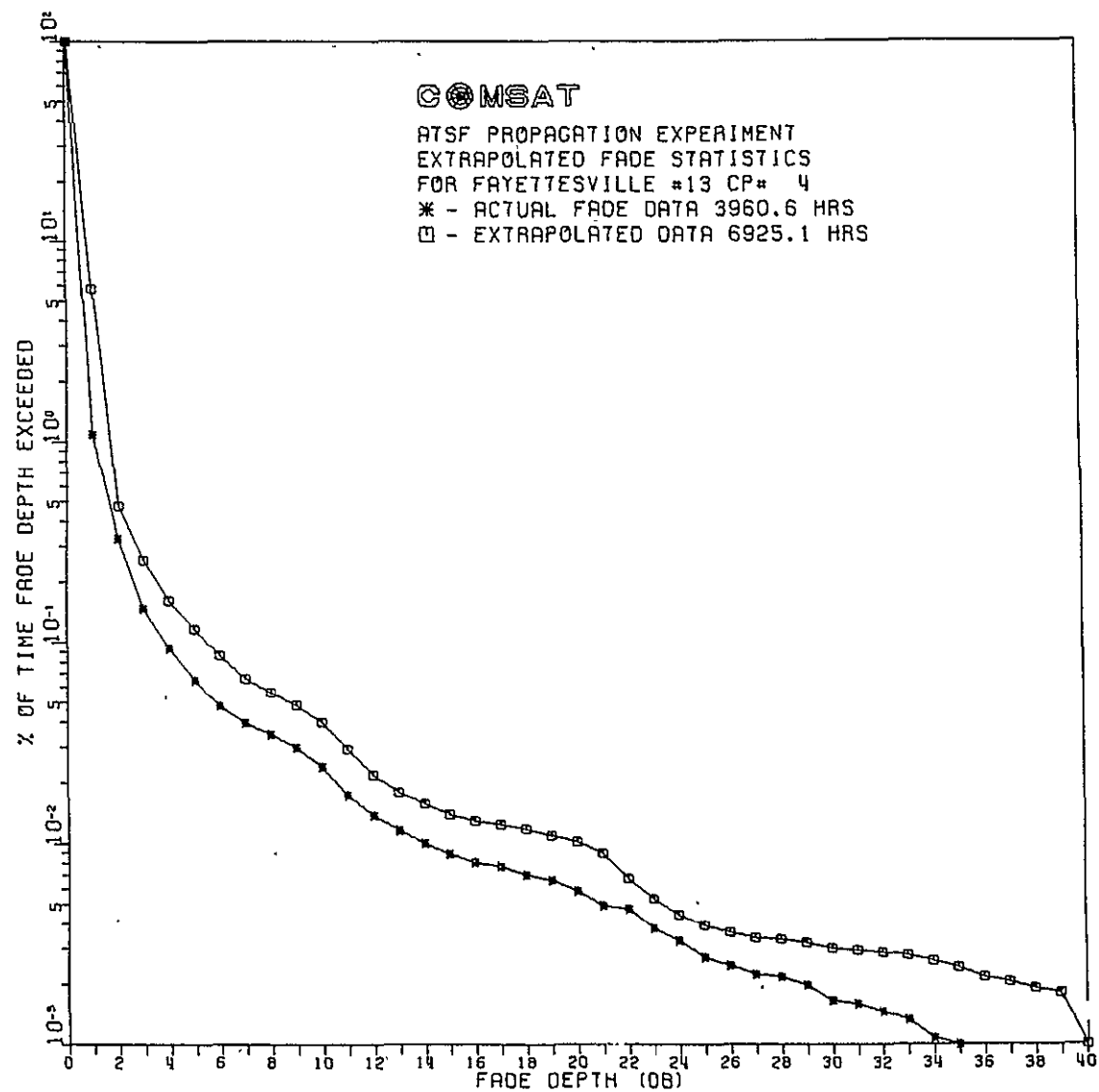


Figure 5-24. Extrapolated Fade Statistics at 13 GHz for Fayetteville #13

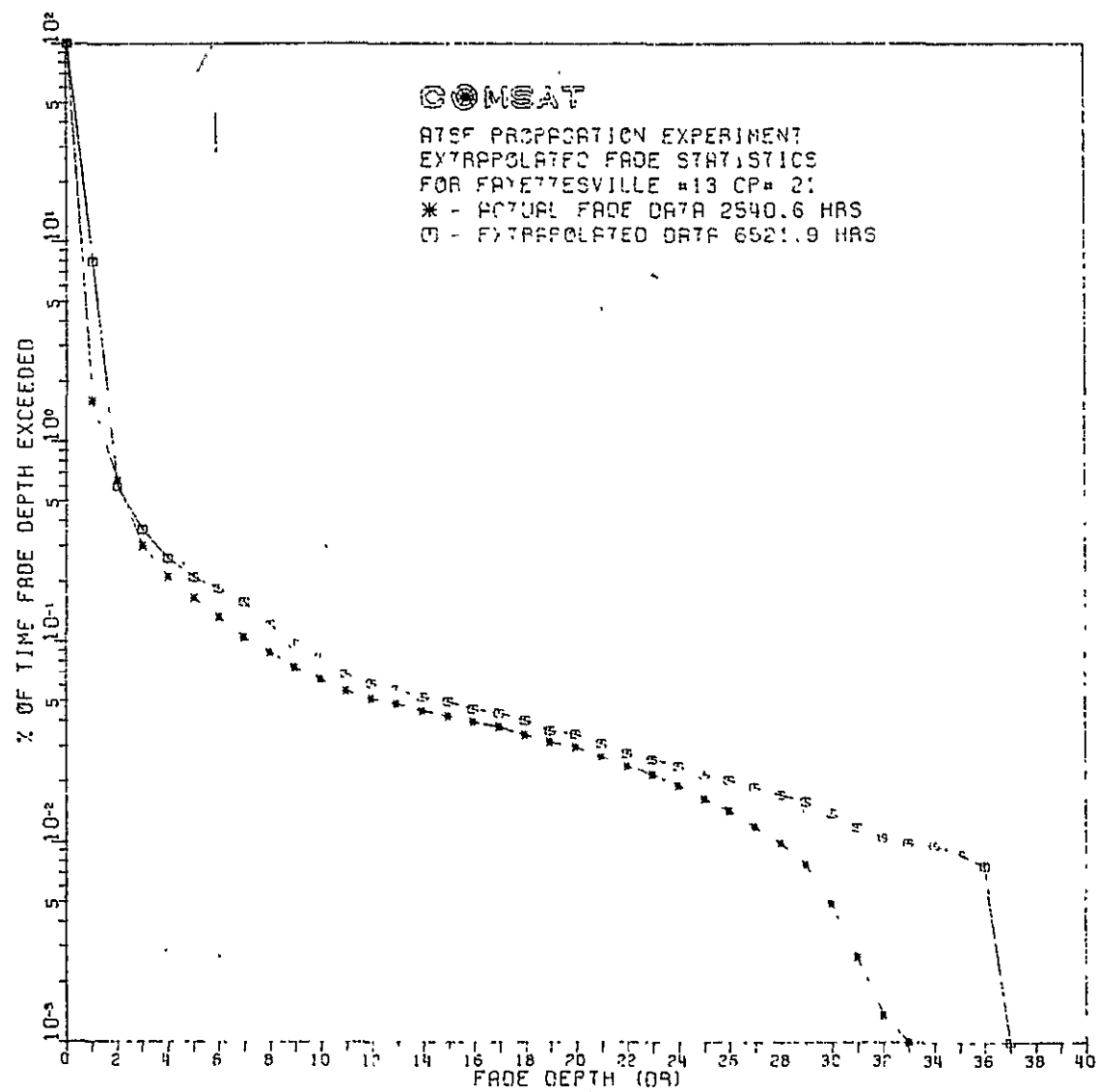
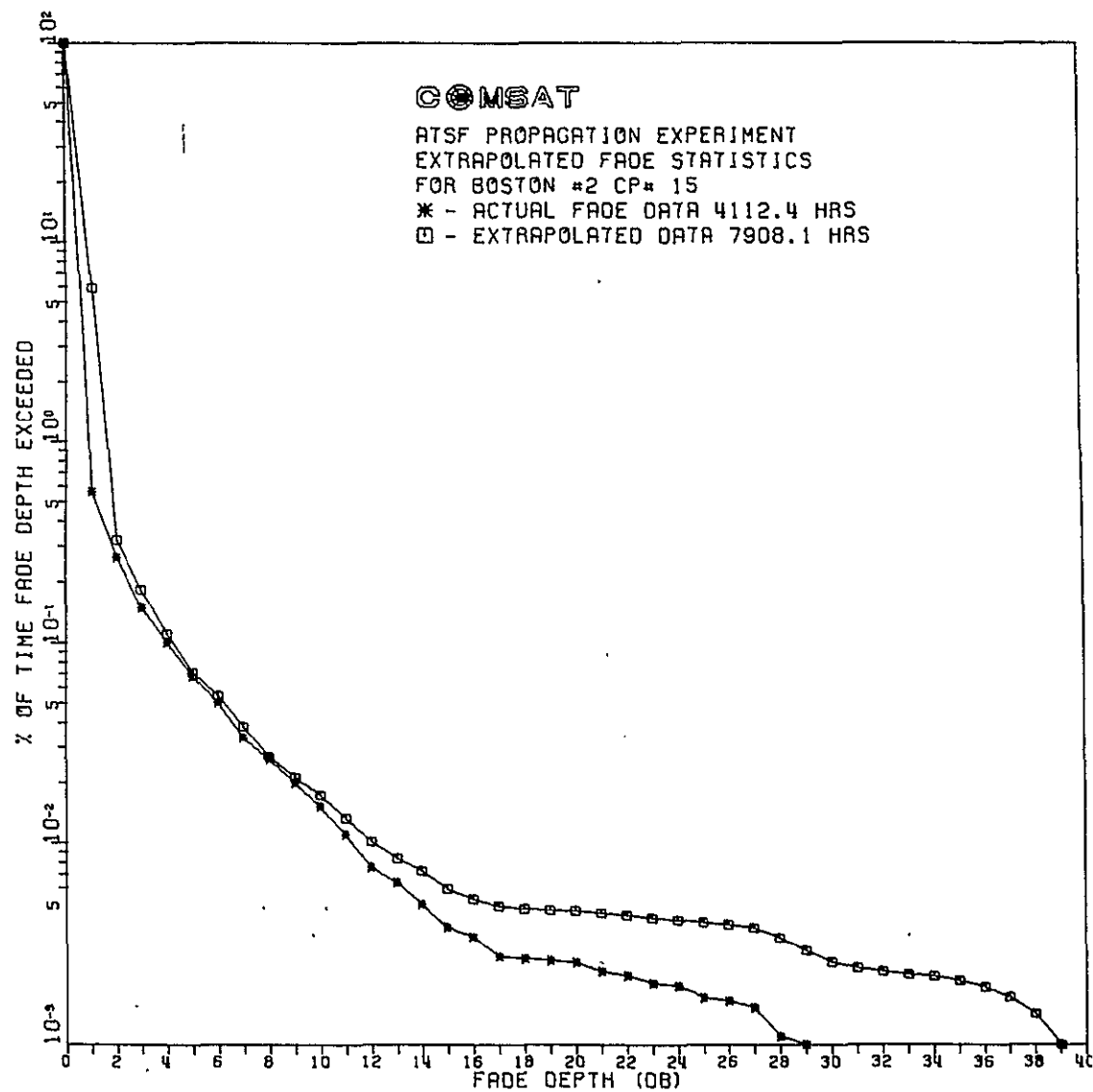


Figure 5-25. Extrapolated Fade Statistics at 18 GHz for Fayetteville #13



5-26. Extrapolated Fade Statistics at 13 GHz for  
 Boston #2 Dual-Frequency Site



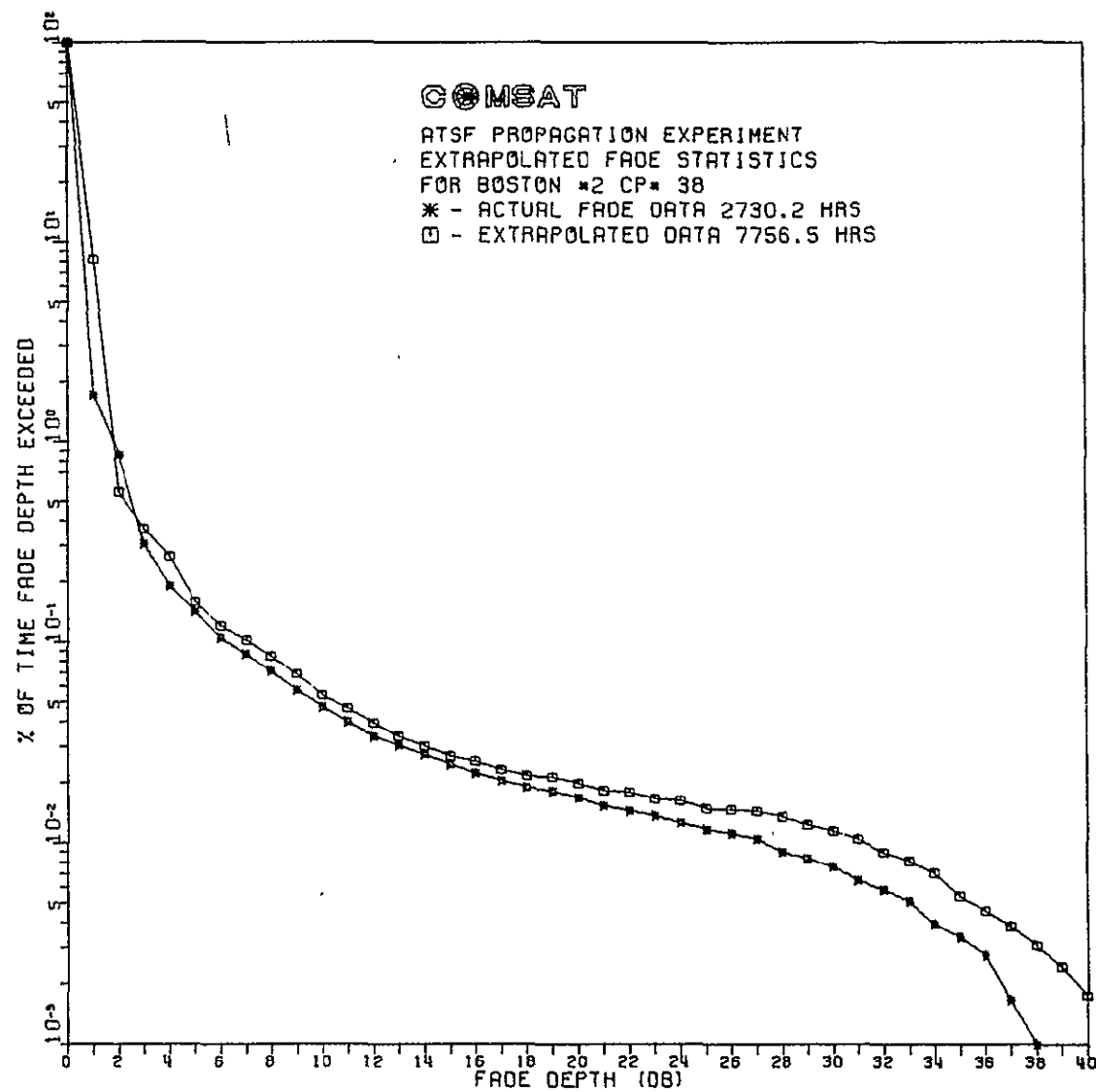


Figure 5-27. Extrapolated Fade Statistics at 18 GHz for Boston #2 Dual-Frequency Site

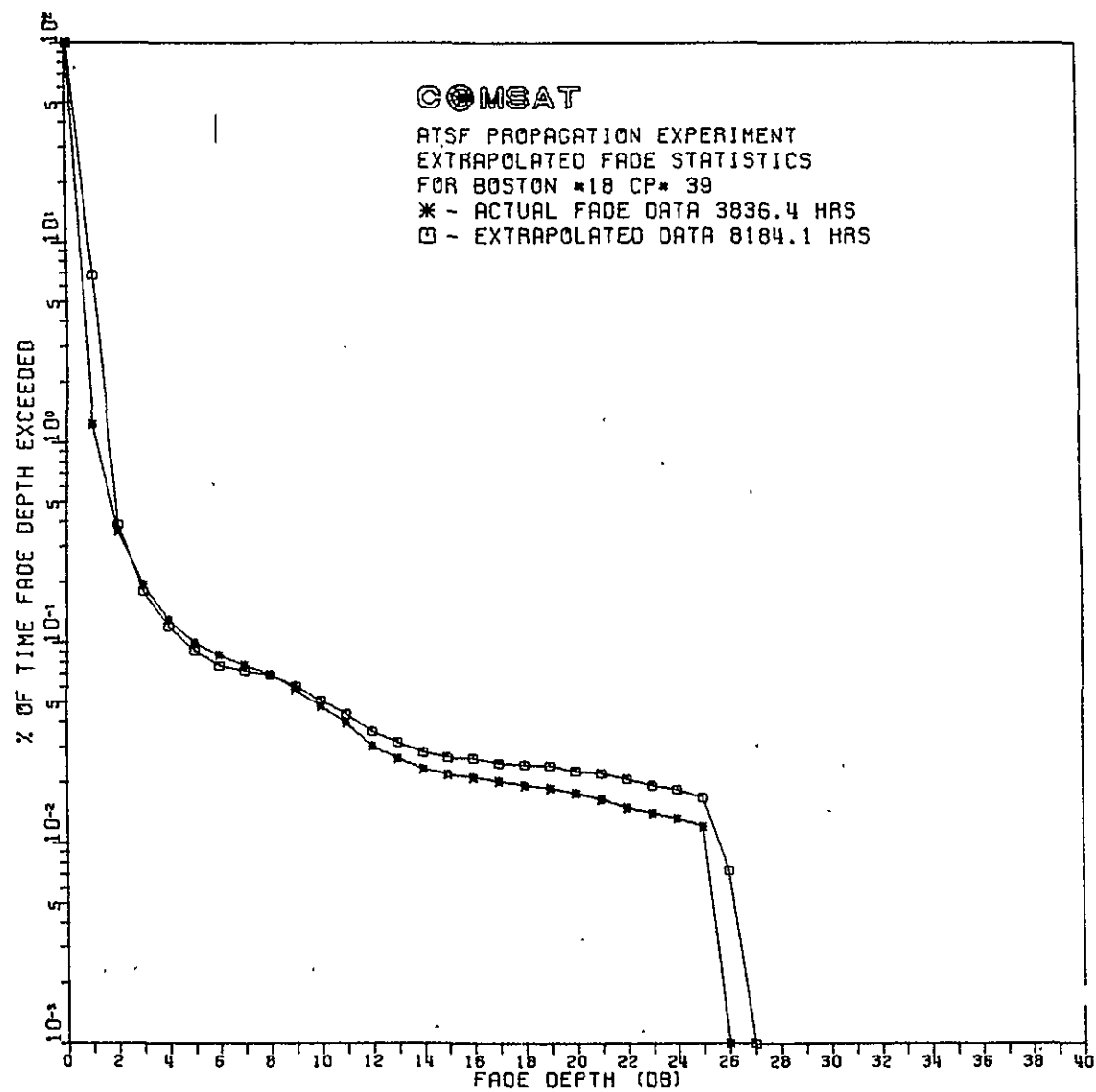


Figure 5-28. Extrapolated Fade Statistics at 18 GHz for Boston #18 Diversity Site

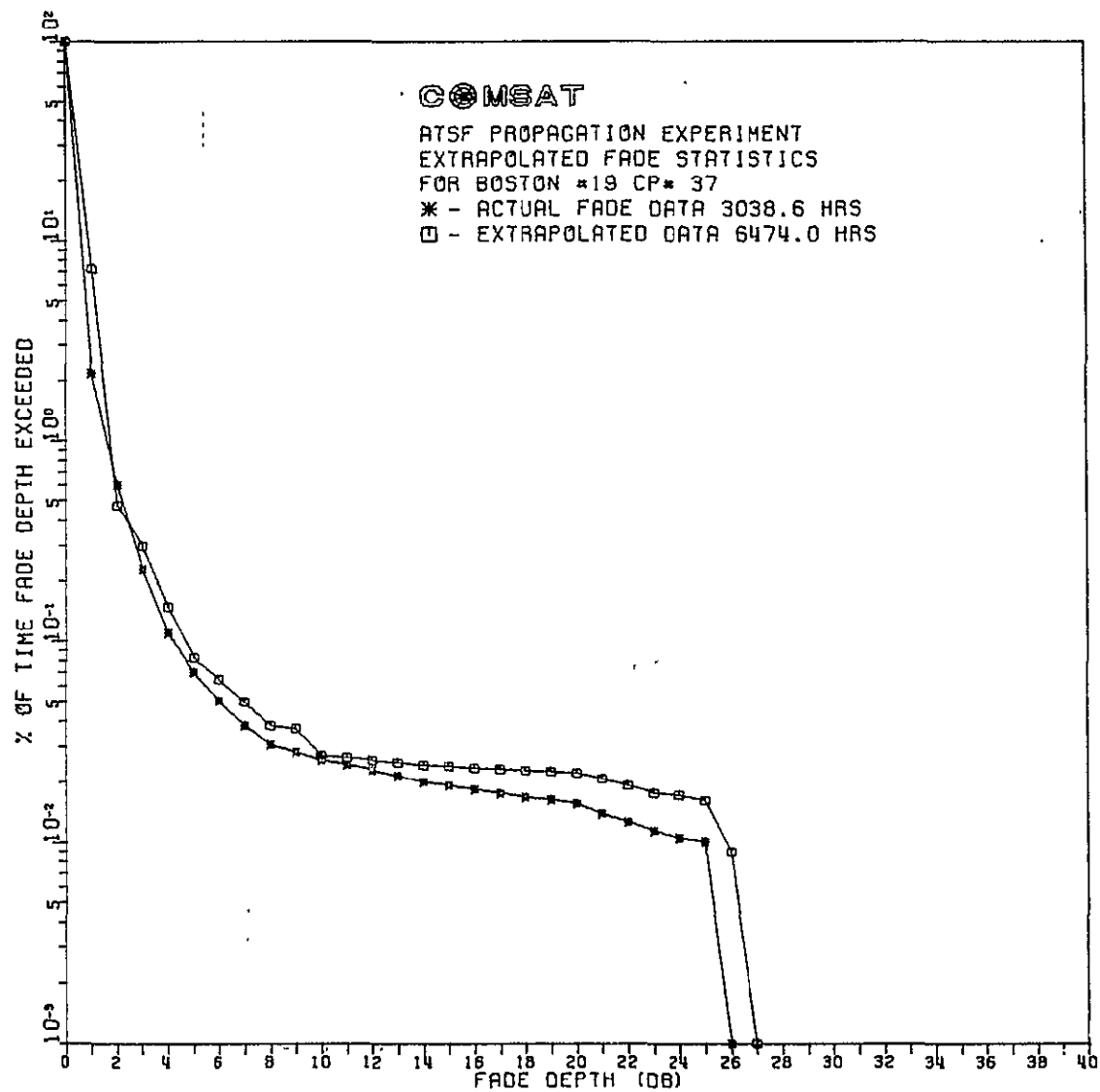


Figure 5-29. Extrapolated Fade Statistics at 18 GHz for Boston #19 Diversity Site

Table 5-43. Extrapolated Fade Statistics

ATSF PROPAGATION EXPERIMENT  
EXTRAPOLATED FADE STATISTICS

-----SITE-----	-----HOURS OF DATA-----					
	CP#	RECORDED	EXTRAPOLATED	CP#	RECORDED	EXTRAPOLATED
BOSTON #2	15	4112.4	7908.1	38	2730.2	7756.5
COLUMBUS #3	14	3426.0	8328.4	35	2584.4	8212.3
STARKVILLE #4	13	3338.5	6856.9	33	2981.4	6690.4
MIAMI #5	12	1805.1	4724.7	30	86.7	4429.8
ITHACA #6	29	0.0	0.0			
DETROIT #7	10	3504.4	4964.7	27	2049.9	3556.2
ANDOVER #8	9	4317.3	4317.3	26	2681.2	2681.2
PHILADELPHIA #9	8	1761.2	2122.7	25	1241.3	1241.3
WASHINGTON #10	7	3666.3	5466.3	24	1267.9	4132.7
NASHVILLE #11	6	1250.9	4825.3	23	2024.5	5003.8
ASHEVILLE #12	5	4450.5	4460.8	22	1617.7	1632.7
FAYETTESVILLE #13	4	3960.6	6525.1	21	2540.6	6521.9
NEW ORLEANS #14	3	1675.9	6306.1	20	1218.7	6293.5
ATLANTA #15	2	3173.3	3173.3	19	1005.6	1005.6
TAMPA #16	1	3374.4	6833.7	18	1460.6	6312.4
BOSTON #17	40	3851.6	3851.6			
BOSTON #18	39	3836.4	8184.1			
BOSTON #19	37	3038.6	6474.0			
WALLOPS ISLAND #20	11	4302.7	6602.5	36	3667.3	6432.5
COLUMBUS #21	34	2698.8	6982.6			
COLUMBUS #22	32	2758.1	7572.5			
COLUMBUS #23	31	2236.8	4424.6			
STARKVILLE #24	28	874.5	2430.9			
STARKVILLE #25	17	1565.9	3894.7			
STARKVILLE #26	16	1878.3	4656.7			

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Table 5-44. Extrapolated Fade Statistics for Fayetteville #13

ATSF PROPAGATION EXPERIMENT  
EXTRAPOLATED FADE STATISTICS FOR FAYETTESVILLE #13

		-----CP# 4-----		-----CP#21-----	
		RECORDED	EXTRAPOLATED	RECORDED	EXTRAPOLATED
	01	100.00	100.00	100.00	100.00
	11	1.0877	5.7672	1.6050	7.8763
	21	.32659	.47569	.63814	.59801
	31	.14720	.25490	.30239	.36401
	41	.09386	.16091	.21166	.26093
	51	.06508	.11692	.16364	.21046
	61	.04816	.08664	.13206	.18293
	71	.03958	.06605	.10490	.15712
	81	.03459	.05626	.08787	.12034
	91	.02992	.04834	.07420	.09655
	101	.02399	.03984	.06426	.08258
	111	.01736	.02935	.05629	.06825
D	121	.01382	.02186	.05156	.06145
E	131	.01161	.01792	.04871	.05713
P	141	.01004	.01572	.04487	.05242
T	151	.00890	.01400	.04221	.04978
H	161	.00808	.01297	.03956	.04573
	171	.00770	.01247	.03729	.04371
O	181	.00701	.01179	.03415	.04021
F	191	.00656	.01098	.03139	.03573
	201	.00581	.01023	.02972	.03435
F	211	.00492	.00898	.02647	.03091
A	221	.00473	.00672	.02352	.02748
D	231	.00379	.00535	.02165	.02573
E	241	.00328	.00443	.01909	.02372
	251	.00271	.00393	.01633	.02163
D	261	.00246	.00362	.01427	.02027
B	271	.00221	.00339	.01191	.01861
	281	.00215	.00333	.00984	.01708
	291	.00196	.00320	.00768	.01587
	301	.00164	.00300	.00492	.01386
	311	.00158	.00294	.00266	.01181
	321	.00145	.00287	.00138	.01053
	331	.00133	.00277	.00079	.00991
	341	.00107	.00261	.00059	.00962
	351	.00082	.00242	.00010	.00863
	361	.00038	.00217	.00000	.00753
	371	.00025	.00205	.00000	.00000
	381	.00006	.00190	.00000	.00000
	391	.00000	.00180	.00000	.00000
	401	.00000	.00000	.00000	.00000

Table 5-45. Extrapolated Fade Statistics  
for Boston #2

ATSF PROPAGATION EXPERIMENT				
EXTRAPOLATED FADE STATISTICS FOR BOSTON #2				
-----CP#15-----		-----CP#38-----		
	RECORDED	EXTRAPOLATED	RECORDED	EXTRAPOLATED
0	100.00	100.00	100.00	100.00
1	.56335	5.9054	1.7046	8.1889
2	.26444	.32301	.85423	.55727
3	.14949	.18313	.30629	.36440
4	.10043	.11065	.18991	.26485
5	.06851	.07124	.14083	.15723
6	.05082	.05457	.10475	.11967
7	.03374	.03831	.08662	.10152
8	.02626	.02688	.07106	.08476
9	.02000	.02120	.05732	.06865
10	.01520	.01725	.04734	.05386
11	.01100	.01337	.03974	.04650
D 12	.00760	.01020	.03361	.03945
E 13	.00638	.00840	.03031	.03362
P 14	.00498	.00728	.02738	.03025
T 15	.00383	.00594	.02454	.02691
H 16	.00340	.00528	.02216	.02541
17	.00274	.00488	.02033	.02308
O 18	.00267	.00474	.01886	.02152
F 19	.00261	.00466	.01804	.02123
20	.00255	.00463	.01667	.01971
F 21	.00231	.00450	.01520	.01816
A 22	.00219	.00438	.01438	.01787
D 23	.00201	.00424	.01355	.01654
E 24	.00195	.00415	.01254	.01619
25	.00170	.00403	.01163	.01483
D 26	.00164	.00394	.01108	.01463
B 27	.00152	.00378	.01044	.01441
28	.00109	.00336	.00897	.01351
29	.00085	.00294	.00833	.01229
30	.00073	.00257	.00760	.01142
31	.00073	.00240	.00650	.01042
32	.00055	.00231	.00586	.00898
33	.00055	.00222	.00513	.00811
34	.00049	.00219	.00394	.00708
35	.00043	.00208	.00339	.00542
36	.00036	.00192	.00275	.00461
37	.00018	.00171	.00165	.00385
38	.00006	.00142	.00092	.00307
39	.00006	.00003	.00055	.00242
40	.00006	.00003	.00009	.00174

Table 5-46. Extrapolated Fade Statistics  
for Boston #18

ATSF PROPAGATION EXPERIMENT  
EXTRAPOLATED FADE STATISTICS FOR BOSTON #18

-----CP#39-----		
	RECORDED	EXTRAPOLATED
0	100.00	100.00
1	1.2338	6.8085
2	.35736	.38541
3	.19439	.17850
4	.12935	.12017
5	.10022	.09096
6	.08641	.07578
7	.07728	.07251
8	.06927	.06875
9	.05871	.06046
10	.04757	.05127
11	.03955	.04365
D 12	.03017	.03559
E 13	.02633	.03158
P 14	.02333	.02824
T 15	.02190	.02660
H 16	.02111	.02623
17	.02020	.02484
O 18	.01922	.02438
F 19	.01864	.02410
20	.01759	.02265
F 21	.01642	.02210
A 22	.01499	.02073
D 23	.01401	.01924
E 24	.01329	.01839
25	.01212	.01681
D 26	.00000	.00732
B 27	.00000	.00000
28	.00000	.00000
29	.00000	.00000
30	.00000	.00000
31	.00000	.00000
32	.00000	.00000
33	.00000	.00000
34	.00000	.00000
35	.00000	.00000
36	.00000	.00000
37	.00000	.00000
38	.00000	.00000
39	.00000	.00000
40	.00000	.00000

Table 5-47. Extrapolated Fade Statistics  
for Boston #19

ATSF PROPAGATION EXPERIMENT EXTRAPOLATED FADE STATISTICS FOR BOSTON #19		
-----CP#37-----		
	RECORDED	EXTRAPOLATED
01	100.00	100.00
11	2.1613	7.2143
21	.59929	.47277
31	.22749	.29827
41	.10951	.14818
51	.06985	.08247
61	.05052	.06443
71	.03793	.04992
81	.03077	.03797
91	.02822	.03677
101	.02575	.02702
111	.02444	.02640
D 121	.02287	.02566
E 131	.02139	.02497
P 141	.01999	.02431
T 151	.01917	.02393
H 161	.01827	.02350
171	.01744	.02312
D 181	.01670	.02277
F 191	.01621	.02254
201	.01547	.02219
F 211	.01382	.02066
A 221	.01259	.01911
D 231	.01144	.01761
E 241	.01053	.01718
251	.01012	.01612
D 261	.00000	.00896
B 271	.00000	.00000
281	.00000	.00000
291	.00000	.00000
301	.00000	.00000
311	.00000	.00000
321	.00000	.00000
331	.00000	.00000
341	.00000	.00000
351	.00000	.00000
361	.00000	.00000
371	.00000	.00000
381	.00000	.00000
391	.00000	.00000
401	.00000	.00000



summary of the hours of data processed for each carrier and the total processed time with extrapolation is given in Table 5-43.

The cumulative attenuation statistics for the Fayetteville slant path and carriers are listed in Table 5-44 and the data is plotted for the 13-GHz carrier in Figure 5-24; the 18 GHz carrier data is plotted in Figure 5-25.

The cumulative attenuation statistics for the Boston dual-frequency path is given in Table 5-45 and the plots are shown in Figures 5-26 and 5-27. The cumulative attenuation statistics for the two diversity GTT sites where processible rain data was collected are given in Tables 5-46 and 5-47 and the plots are shown in Figures 5-28 and 5-29.

From examination of the coincident rain exceedance levels plotted in Figure 5-20, it can be seen that the extrapolated fade exceedance levels shown in Figure 5-24 for the Fayetteville 13-GHz carrier are significantly worse than the measured levels (rising from about 14 dB, measured, to about 20 dB for the 0.01 percent-of-the time exceedance level). This is in agreement with the fact that the heavy thunderstorms of May, June and July had made their presence felt more or less fully. What has happened in Figure 5-25 for the 18-GHz data is also interesting. Because the measured data for 18-GHz tails off so sharply from just above 0.01 percent-of-the time, i.e. there was so little data, and there was much more heavy rain measured when no processible 18-GHz data was collected, the extrapolated curve cuts-off abruptly for lack of data for the set a. data previously described. Examination of the extrapolated cumulative fade statistics in comparison with the rain data for the Boston carriers shows similar increase and cut-off problems.

The extrapolated rain statistics for all sites are listed in Table 5-48. The extrapolated cumulative rain statistics for the Fayetteville and Boston sites are plotted in Figures 5-30 through 5-33 and tabulated in Tables 5-49 through 5-52. As can be seen from the legend of Figure 5-32 for measured and extrapolated hours of rain data collected there may be as much as 25 percent more hours. However, the impact, as can be seen from the figures, is slight. For Fayetteville, the exceedance levels for a given percent-of-the time are reduced at the highest rain rate levels. However, for the Boston sites the levels are virtually unchanged.

#### 5.6 DISCUSSION OF DATA LIMITATIONS

The following paragraphs provide a summary of the limitations of the data base collected during the CPE due to the amount of data collected, the duration of the data collection process, and the complexity of the data acquisition and reduction processes. These are discussed in more detail in the Final Hardware Report<sup>[4]</sup>, the Data Processing Report<sup>[5]</sup>, or in sections of this volume and are included here so that the limitations of the results presented in Part II can be better understood. The following factors are the major limitations related to the amount and duration of data collection:

- a. The duration of the experiment was from July 1974 to May 1975, excluding a period of intense rainfall for the eastern U.S.A. (mid-May to mid-July).
- b. changes of satellite attitude to accomodate other ATS-6 experiments resulted in loss of data; and
- c. the amount of data collected was reduced by equipment downtime.

Table 5-48. Extrapolated Rain Statistics

ATSF PROPAGATION EXPERIMENT  
 EXTRAPOLATED RAIN STATISTICS  
 FROM: MAY 19, 1974  
 TO: MAY 31, 1975

-----SITE-----	ACTUAL DATA	-----HOURS OF DATA-----		EXTRAPOLATED	
		CP#	HOURS	CP#	HOURS
BOSTON #2	7115.0	15	7961.2	38	7978.9
COLUMBUS #3	7999.0	14	8730.5	35	8554.0
STARKVILLE #4	6366.2	13	7186.4	33	6893.6
MIAMI #5	4413.5	12	4960.1	30	4429.7
ITHACA #6	1943.5	29	1943.5		
DETROIT #7	1948.2	10	4964.4	27	3556.1
ANDOVER #8	0.0	9	0.0	26	0.0
PHILADELPHIA #9	453.7	8	2122.7	25	453.7
WASHINGTON #10	3651.7	7	5667.1	24	4299.2
NASHVILLE #11	4567.9	6	5133.1	23	5269.3
ASHEVILLE #12	48.0	5	4460.8	22	1632.7
FAYETTESVILLE #13	5354.1	4	6938.2	21	6589.7
NEW ORLEANS #14	6026.7	3	6589.9	20	6293.5
ATLANTA #15	641.5	2	641.5	19	641.5
TAMPA #16	6058.0	1	7177.0	18	6574.0
BOSTON #17	0.0	40	0.0		
BOSTON #18	7835.7	39	8192.6		
BOSTON #19	6219.5	37	6482.5		
WALLOPS ISLAND #20	5145.9	11	6849.1	36	6691.4
COLUMBUS #21	6667.3	34	6982.6		
COLUMBUS #22	7199.6	32	7572.5		
COLUMBUS #23	4289.5	31	4424.6		
STARKVILLE #24	2048.6	28	2430.9		
STARKVILLE #25	3270.0	17	3895.0		
STARKVILLE #26	3988.5	16	4670.2		

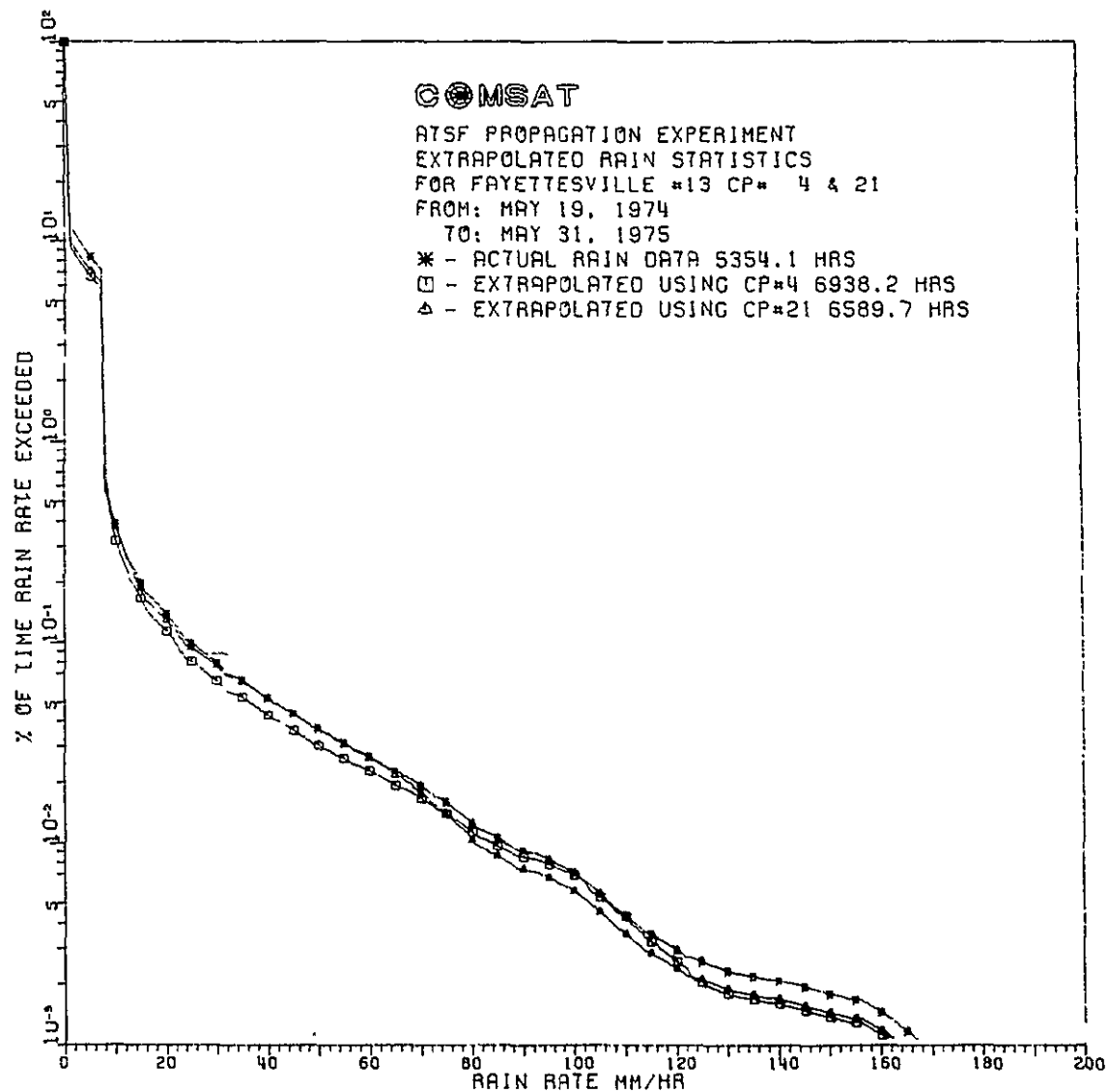


Figure 5-30. Extrapolated Rain Statistics at 13 GHz for Fayetteville  
#13 Dual-Frequency Site

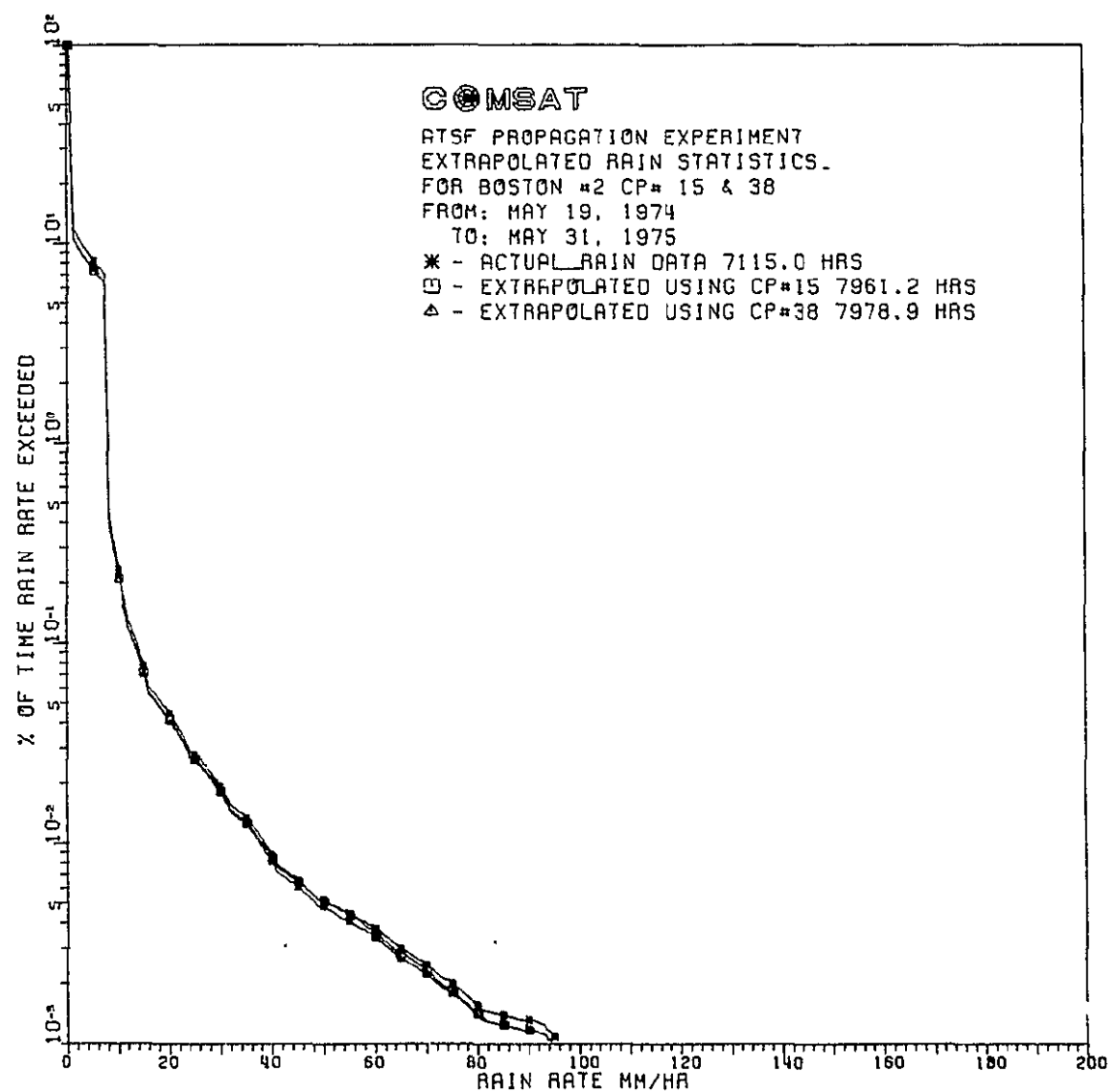


Figure 5-31. Extrapolated Rain Statistics for Boston #2 Dual-Frequency Site

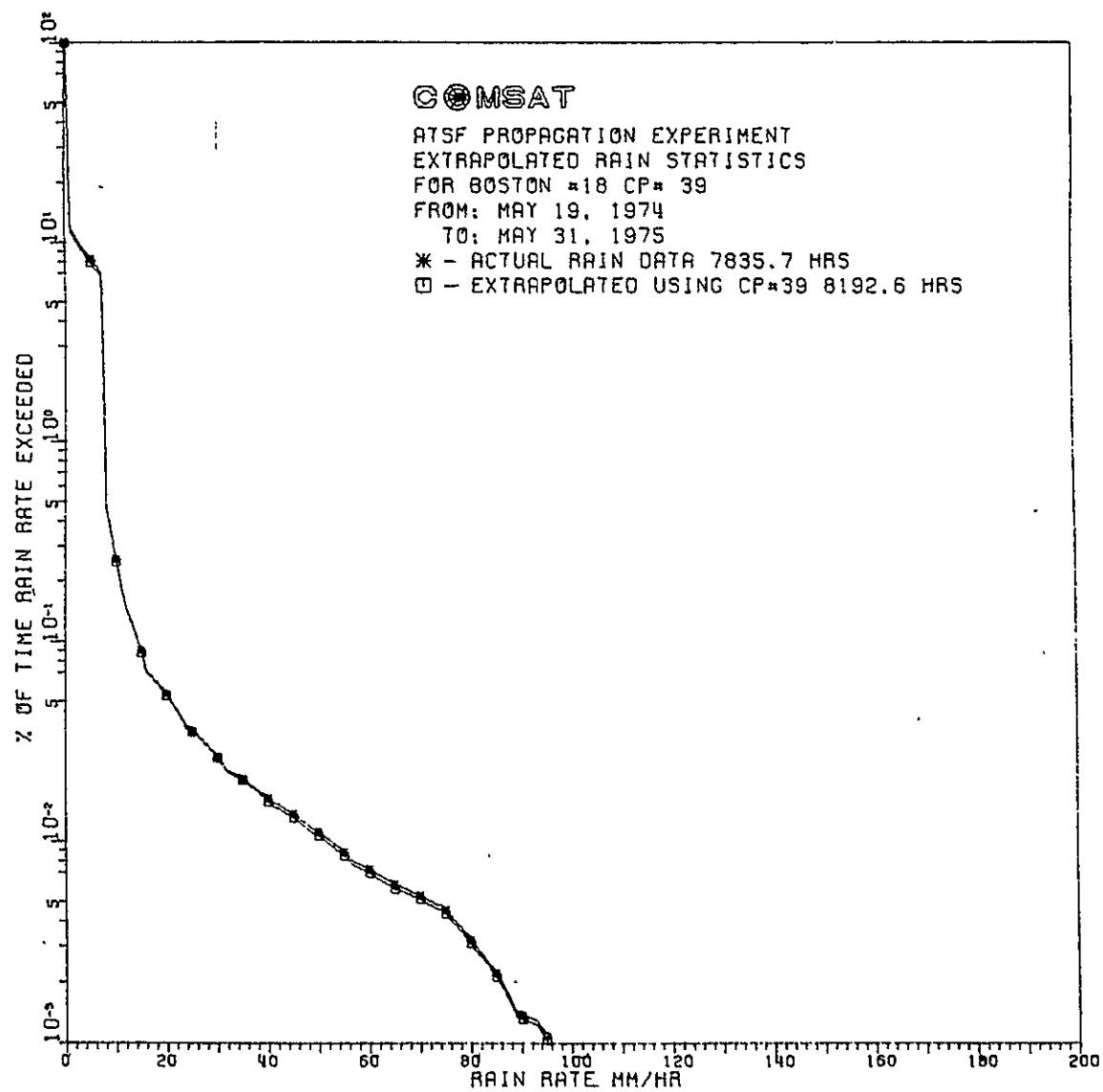


Figure 5-32. Extrapolated Rain Statistics for Boston #18 Diversity Site

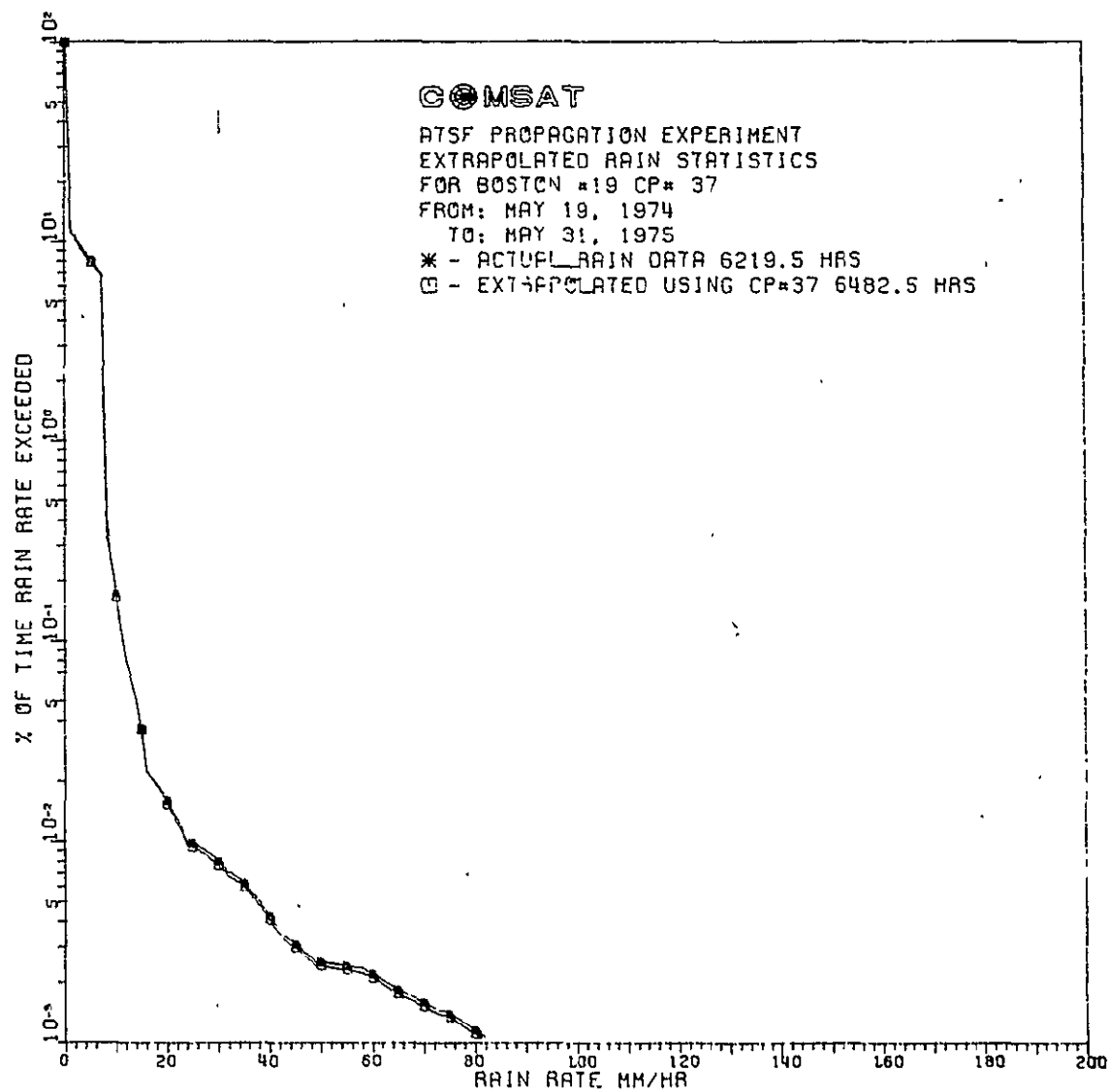


Figure 5-33. Extrapolated Rain Statistics for Boston #19 at Diversity Site

Table 5-49. Extrapolated Rain Statistics  
for Fayetteville #13

ATSF PROPAGATION EXPERIMENT  
EXTRAPOLATED RAIN STATISTICS FOR FAYETTEVILLE #13  
FROM: MAY 19, 1974  
TO: MAY 31, 1975

	ACTUAL RAIN DATA TIME	EXTRAPOLATED USING CP# 4	EXTRAPOLATED USING CP#21
01	100.00	100.00	100.00
21	10.713	8.4919	9.0453
41	8.9647	7.1427	7.6247
61	7.7150	6.1783	6.6093
81	.56259	.65884	.79798
101	.38620	.32055	.37407
121	.27418	.23410	.26321
141	.22272	.18408	.21032
161	.17348	.14609	.15947
181	.15705	.12811	.14612
201	.13810	.11349	.12856
251	.09846	.08037	.09411
301	.07839	.06413	.07652
351	.06495	.05329	.06370
401	.05264	.04311	.05237
451	.04395	.03608	.04372
R 501	.03662	.03042	.03662
A 551	.03123	.02626	.03099
I 601	.02679	.02284	.02640
N 651	.02243	.01925	.02168
701	.01918	.01668	.01760
R 751	.01595	.01407	.01387
A 801	.01260	.01141	.01046
T 851	.01058	.00968	.00860
E 901	.00911	.00851	.00740
951	.00827	.00786	.00672
M 1001	.00711	.00696	.00577
M 1051	.00563	.00539	.00457
1101	.00440	.00433	.00357
P 1151	.00353	.00326	.00287
E 1201	.00297	.00262	.00241
R 1251	.00261	.00205	.00212
1301	.00233	.00179	.00189
H 1351	.00219	.00169	.00178
R 1401	.00207	.00160	.00168
1451	.00193	.00149	.00157
1501	.00179	.00138	.00146
1551	.00168	.00130	.00137
1601	.00146	.00112	.00118
1651	.00118	.00091	.00096
1701	.00090	.00069	.00073
1751	.00084	.00065	.00068
1801	.00084	.00065	.00068
1851	.00056	.00043	.00046
1901	.00028	.00022	.00023
1951	.00000	.00000	.00000
2001	.00000	.00000	.00000



Table 5-50. Extrapolated Rain Statistics  
for Boston #2

ATSF PROPAGATION EXPERIMENT  
EXTRAPOLATED RAIN STATISTICS FOR BOSTON #2  
FROM: MAY 19, 1974  
TO: MAY 31, 1975

	ACTUAL RAIN DATA TIME	EXTRAPOLATED USING CP#15	EXTRAPOLATED USING CP#38
01	100.00	100.00	100.00
21	10.567	9.4636	9.5118
41	8.8193	7.9020	7.9537
61	7.5705	6.7859	6.8401
81	.40947	.38602	.45446
101	.22968	.20863	.20678
121	.13049	.11967	.11771
141	.09484	.08746	.08583
161	.05980	.05583	.05455
181	.05244	.04894	.04795
201	.04437	.04172	.04072
251	.02766	.02644	.02570
301	.01915	.01818	.01776
351	.01332	.01256	.01222
401	.00873	.00843	.00803
451	.00652	.00642	.00603
R 501	.00514	.00513	.00478
A 551	.00443	.00437	.00404
I 601	.00374	.00350	.00337
N 651	.00298	.00282	.00266
701	.00248	.00231	.00221
R 751	.00199	.00181	.00177
A 801	.00157	.00143	.00140
T 851	.00140	.00125	.00125
E 901	.00132	.00118	.00117
951	.00108	.00097	.00096
M 1001	.00064	.00058	.00057
M 1051	.00020	.00018	.00018
1101	.00000	.00000	.00000
P 1151	.00000	.00000	.00000
E 1201	.00000	.00000	.00000
R 1251	.00000	.00000	.00000
1301	.00000	.00000	.00000
H 1351	.00000	.00000	.00000
R 1401	.00000	.00000	.00000
1451	.00000	.00000	.00000
1501	.00000	.00000	.00000
1551	.00000	.00000	.00000
1601	.00000	.00000	.00000
1651	.00000	.00000	.00000
1701	.00000	.00000	.00000
1751	.00000	.00000	.00000
1801	.00000	.00000	.00000
1851	.00000	.00000	.00000
1901	.00000	.00000	.00000
1951	.00000	.00000	.00000
2001	.00000	.00000	.00000

Table 5-51. Extrapolated Rain Statistics  
for Boston #18

ATSF PROPAGATION EXPERIMENT  
EXTRAPOLATED RAIN STATISTICS FOR BOSTON #18  
FROM: MAY 19, 1974  
TO: MAY 31, 1975

	ACTUAL RAIN DATA TIME	EXTRAPOLATED USING CP#39
01	100.00	100.00
21	10.646	10.221
41	8.8870	8.5390
61	7.6307	7.3374
81	.46747	.48614
101	.25783	.25121
121	.14823	.14388
141	.10930	.10607
161	.07115	.06943
181	.06361	.06200
201	.05471	.05339
251	.03597	.03526
301	.02665	.02619
351	.02058	.02014
401	.01643	.01572
451	.01369	.01309
R 501	.01116	.01067
A 551	.00884	.00846
I 601	.00728	.00697
N 651	.00610	.00583
701	.00538	.00514
R 751	.00455	.00436
A 801	.00326	.00311
T 851	.00221	.00212
E 901	.00138	.00132
951	.00109	.00104
M 1001	.00064	.00061
M 1051	.00024	.00023
1101	.00000	.00000
P 1151	.00000	.00000
E 1201	.00000	.00000
R 1251	.00000	.00000
1301	.00000	.00000
H 1351	.00000	.00000
R 1401	.00000	.00000
1451	.00000	.00000
1501	.00000	.00000
1551	.00000	.00000
1601	.00000	.00000
1651	.00000	.00000
1701	.00000	.00000
1751	.00000	.00000
1801	.00000	.00000
1851	.00000	.00000
1901	.00000	.00000
1951	.00000	.00000
2001	.00000	.00000

Table 5-52. Extrapolated Rain Statistics  
for Boston #19

ATSF PROPAGAT J EXPERIMENT  
EXTRAPOLATED RAIN STATISTICS FOR BOSTON #19  
FROM: MAY 19, 1974  
TO: MAY 31, 1975

	ACTUAL RAIN DATA TIME	EXTRAPOLATED USING CP#37
01	100.00	100.00
21	10.506	10.156
41	8.7603	8.4812
61	7.5133	7.2848
81	.34983	.41192
101	.17042	.16454
121	.08125	.07900
141	.05152	.05035
161	.02238	.02228
181	.01927	.01895
201	.01604	.01539
251	.00984	.00944
301	.00798	.00766
351	.00620	.00595
401	.00427	.00410
451	.00311	.00298
R 501	.00253	.00243
A 551	.00241	.00231
I 601	.00219	.00211
N 651	.00183	.00176
701	.00159	.00153
R 751	.00140	.00134
A 801	.00116	.00111
T 851	.00092	.00088
E 901	.00072	.00069
951	.00072	.00069
M 1001	.00068	.00065
M 1051	.00043	.00042
1101	.00019	.00019
P 1151	.00000	.00000
E 1201	.00000	.00000
R 1251	.00000	.00000
1301	.00000	.00000
H 1351	.00000	.00000
R 1401	.00000	.00000
1451	.00000	.00000
1501	.00000	.00000
1551	.00000	.00000
1601	.00000	.00000
1651	.00000	.00000
1701	.00000	.00000
1751	.00000	.00000
1801	.00000	.00000
1851	.00000	.00000
1901	.00000	.00000
1951	.00000	.00000
2001	.00000	.00000

Every effort was made to overcome these limitations, i.e., data processing was used to correct for the variations caused by attitude changes to the maximum extent practical by utilization of the telemetry data. Further, the corrected and reduced data was extrapolated to provide statistics for the maximum duration allowable by the data collected. All these factors together can in some cases introduce residual uncertainties. For example, the number of hours of processible data used to obtain the results in Volume II is given along with the data and should be borne in mind when using the data. An extreme case is data on the 18-GHz carrier from Miami (see Figure 5-34) which provided processible data for only 87 hours for the duration of the experiment with resulting attenuation statistics which are correct for the observation period, but high if considered as applying to an entire year.

In addition to the foregoing, the extensive processing of the data necessarily introduced uncertainties which should be considered. Extreme care in data processing, primarily in the manual phase has reduced most of these uncertainties to acceptable levels. An example of such uncertainties is shown in Figures 5-11 through 5-18 where the diversity gain does not continue to improve as expected for higher levels of attenuation. This uncertainty may be attributed to the interaction of the sampling rates of the telemetry data (48 seconds) and the attenuation data (9 seconds) with the data acquisition system. Other examples include:

- a. the higher percent time for the medium attenuation range found in Figure 5-35 for 18-GHz carrier at Philadelphia;
- b. the higher percent time for the low attenuation range in Figure 5-36 for the 13-GHz and Figure 5-37 for the 18-GHz carriers from Andover, which was caused by attenuation of the wet radome on the transmitted carriers.

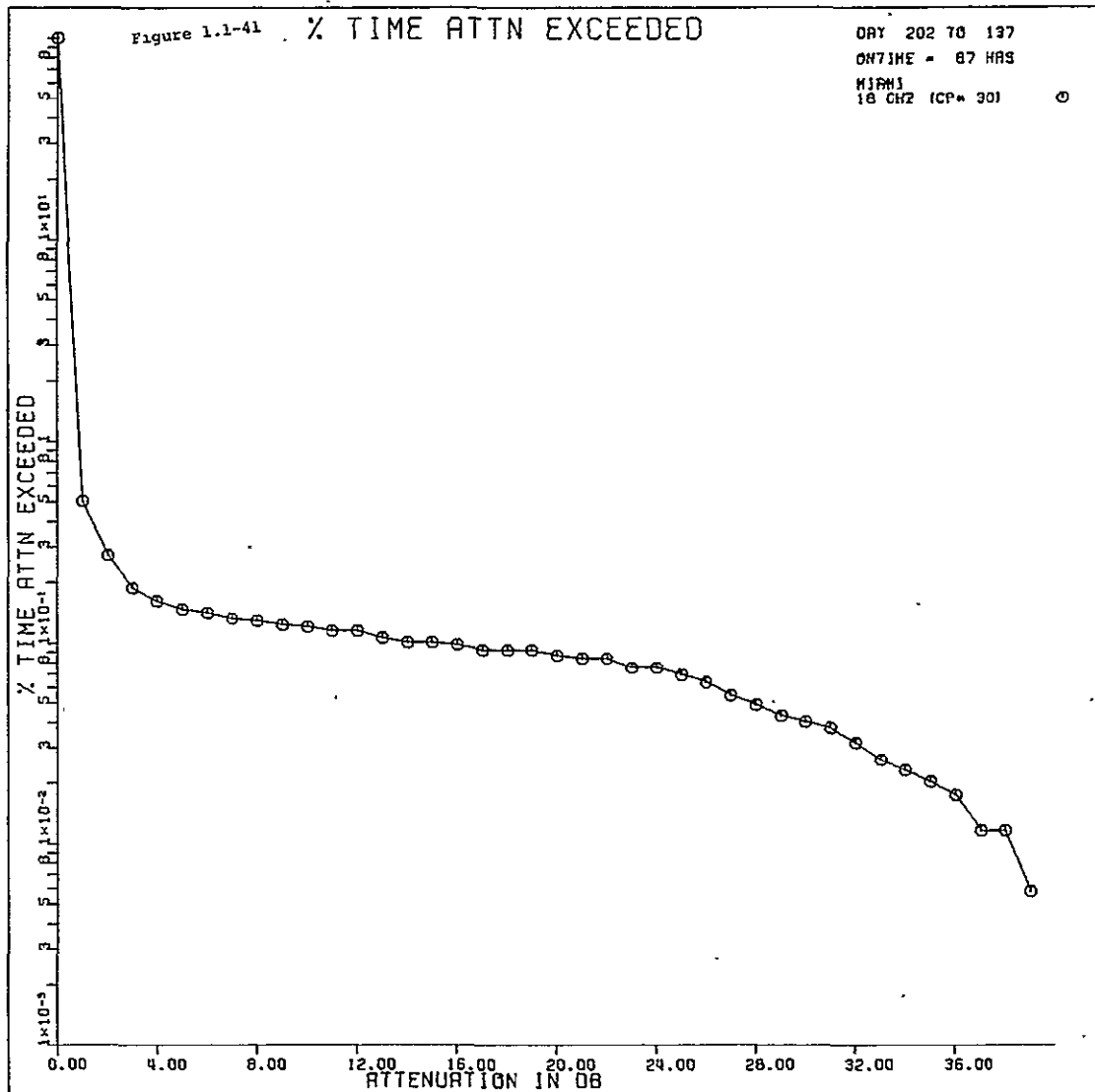


Figure 5-34. Miami, 18 GHz Percent-of-Time Attenuation Exceeded

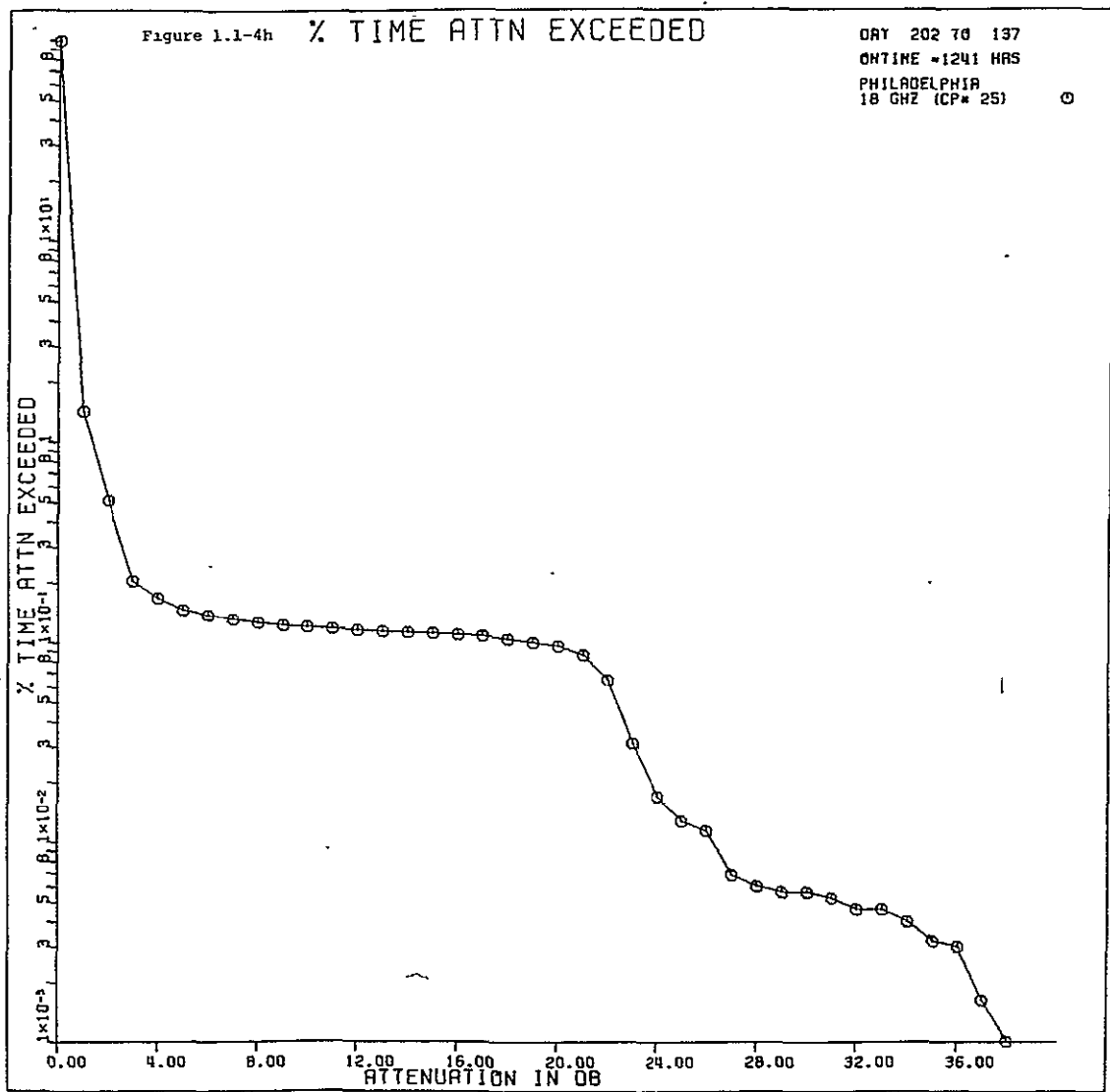


Figure 5-35. Philadelphia, 18 GHz Percent-of-Time Attenuation Exceeded

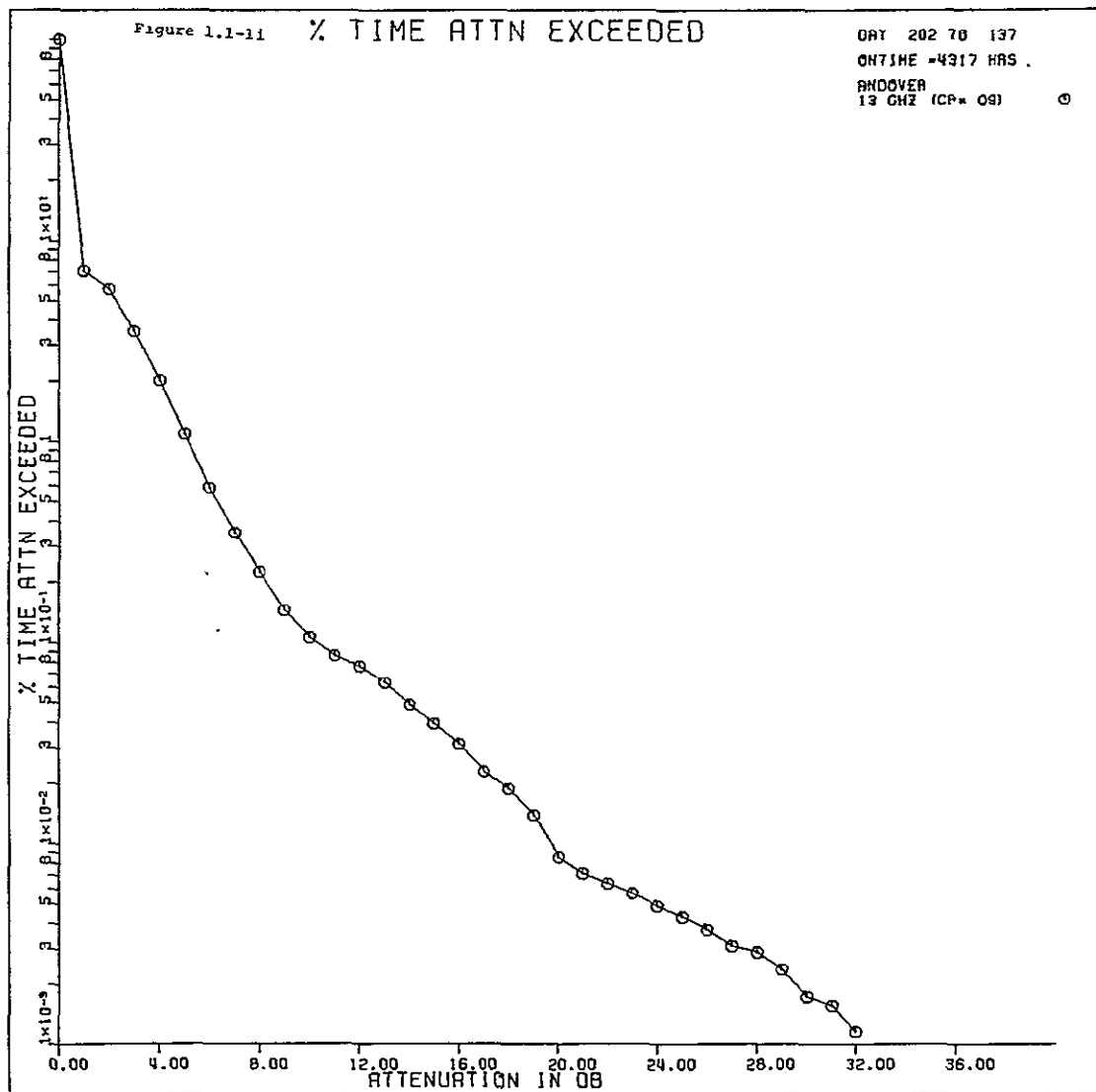


Figure 5-36. Andover, 13 GHz Percent-of-Time Attenuation Exceeded

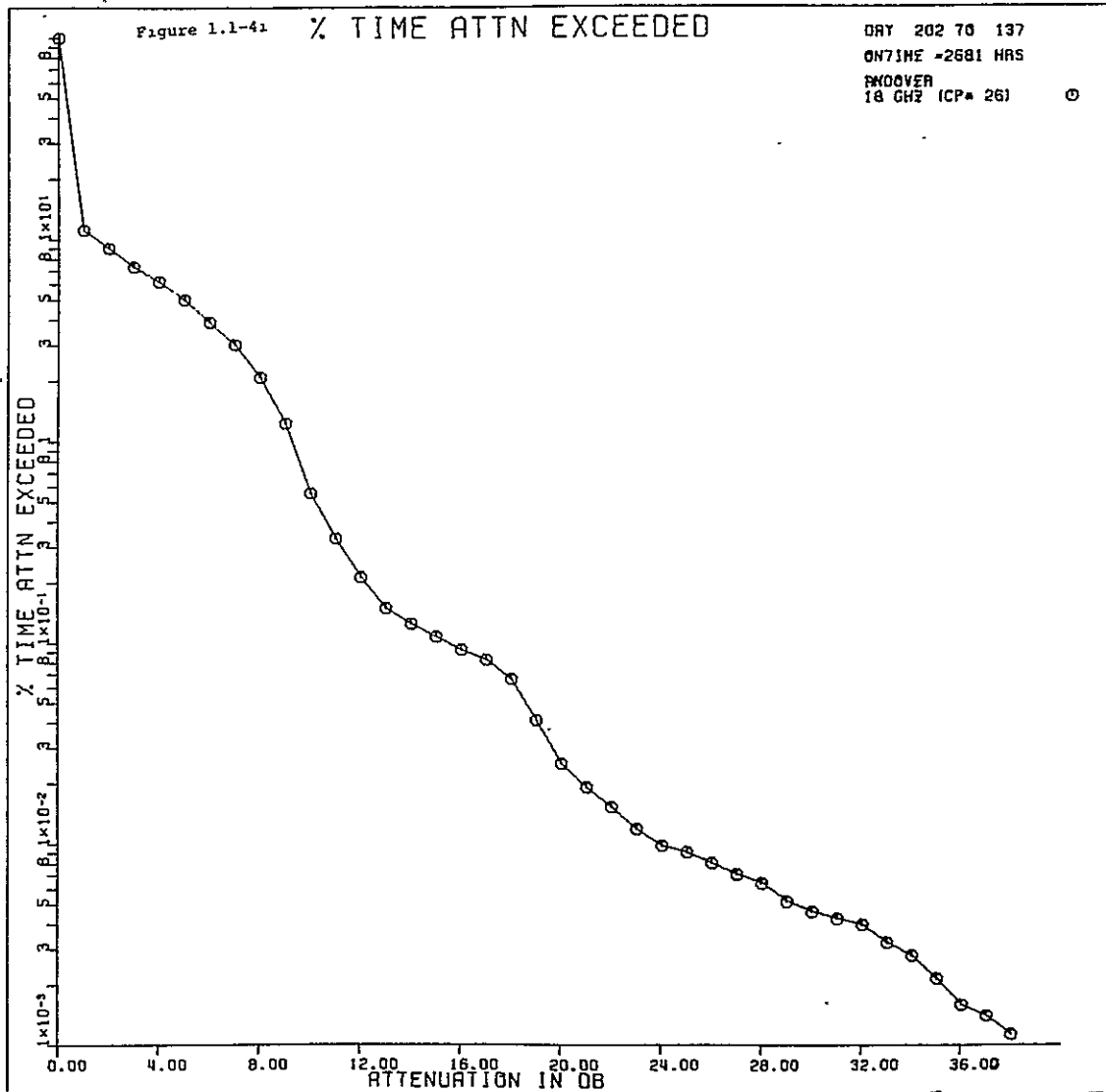


Figure 5-37. Andover, 18 GHz Percent-of-Time Attenuation Exceeded



The computer-analyzed data base has been presented, using as examples the results for the duration of the experiment for the slant paths from the Fayetteville, N.C. dual-frequency site and from the Boston, Mass. diversity sites.

Exceedance plots have been presented for: the individual carriers for the duration of the experiment, the joint on times for the Fayetteville 13- and 18-GHz carriers and for the Boston 18-GHz carriers in diversity pairs (also showing the diversity carrier). Exceedance plots were also given for the point rain rate at the GTT sites. As expected, the exceedance curves are shaped so that they asymptotically approach two lines, as the Rice-Holmberg rain modeling predicts. The data for dual-frequency slant-path at Fayetteville clearly shows the rapid increase in attenuation as a function of frequency, the ratio being established by the correlation of 18- and 13-GHz data at about 1.6 dB/dB for these data.

The effectiveness of diversity in mitigating the attenuation due to rain on slant paths has been demonstrated by the Boston data. By comparing the Fayetteville and Boston data, it has been shown that the higher annual rain and rain-rate characteristic of the Fayetteville region has a marked effect on the 0.01 percent attenuation level (again verifying expected effects on path attenuation statistics predicted by the Rice-Holmberg modeling of point rain-rate statistics). While the data is limited, it is clear from the path attenuation and the point rain data at the Boston sites that there can be a significant variation of total rainfall and rain-rate distribution over an interval of time (of the order of a year). (Whether such variations would hold true over several years remains to be established.)

It has been shown that the point rain rate exceedance statistics can be used to extrapolate the path attenuation exceedance statistics and obtain reasonable results.

Finally, it should be noted that the work discussed herein represents the first use of this large data base. It is expected that the ATS-F 13/18-GHz COMSAT Propagation Experiment data base as analyzed and presented will be directly useful in satellite communications systems design above 10 GHz; but beyond this, the data base will continue to be analyzed to provide further useful information for some time to come.

## 6. ACKNOWLEDGEMENT

In the course of a project like the ATS-F 13/18-GHz COMSAT Propagation Experiment, many people make noteworthy contributions. The success of the project is the sum of these contributions, and the outcome of the project, as represented by the data presented herein (and in Part II) is successful only because of the wholehearted efforts of all of my colleagues, hereby gratefully acknowledged.

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The project was conceived by J. Levatich, E. Robertson and A. Buige. Its early management was conducted by J. Levatich and L. Westerlund. During my tenure as project manager and principal investigator, the project has had the wholehearted

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Geoffrey Hyde.

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